June 14, 1960 R. E. PFITZENMEIER 2,940,262

HYDRAULIC CROSS-REGENERATIVE CIRCUIT

Filed June 13, 1958 2 Sheets-Sheet 1

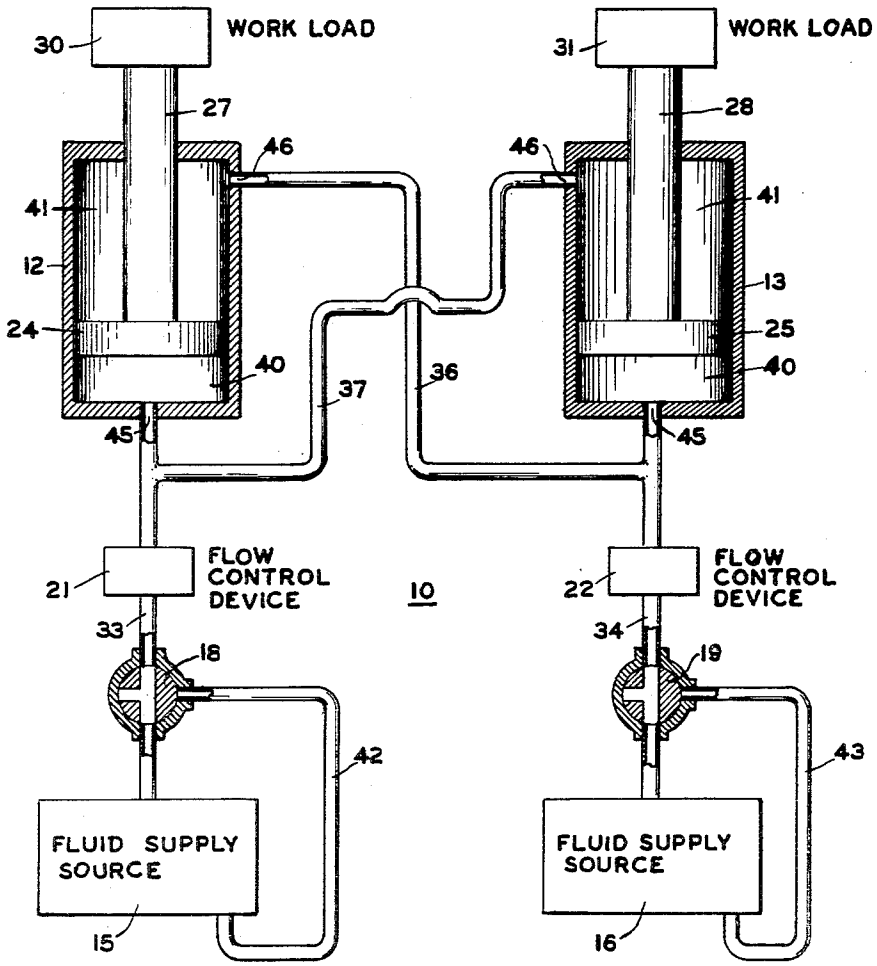


FIG. 1

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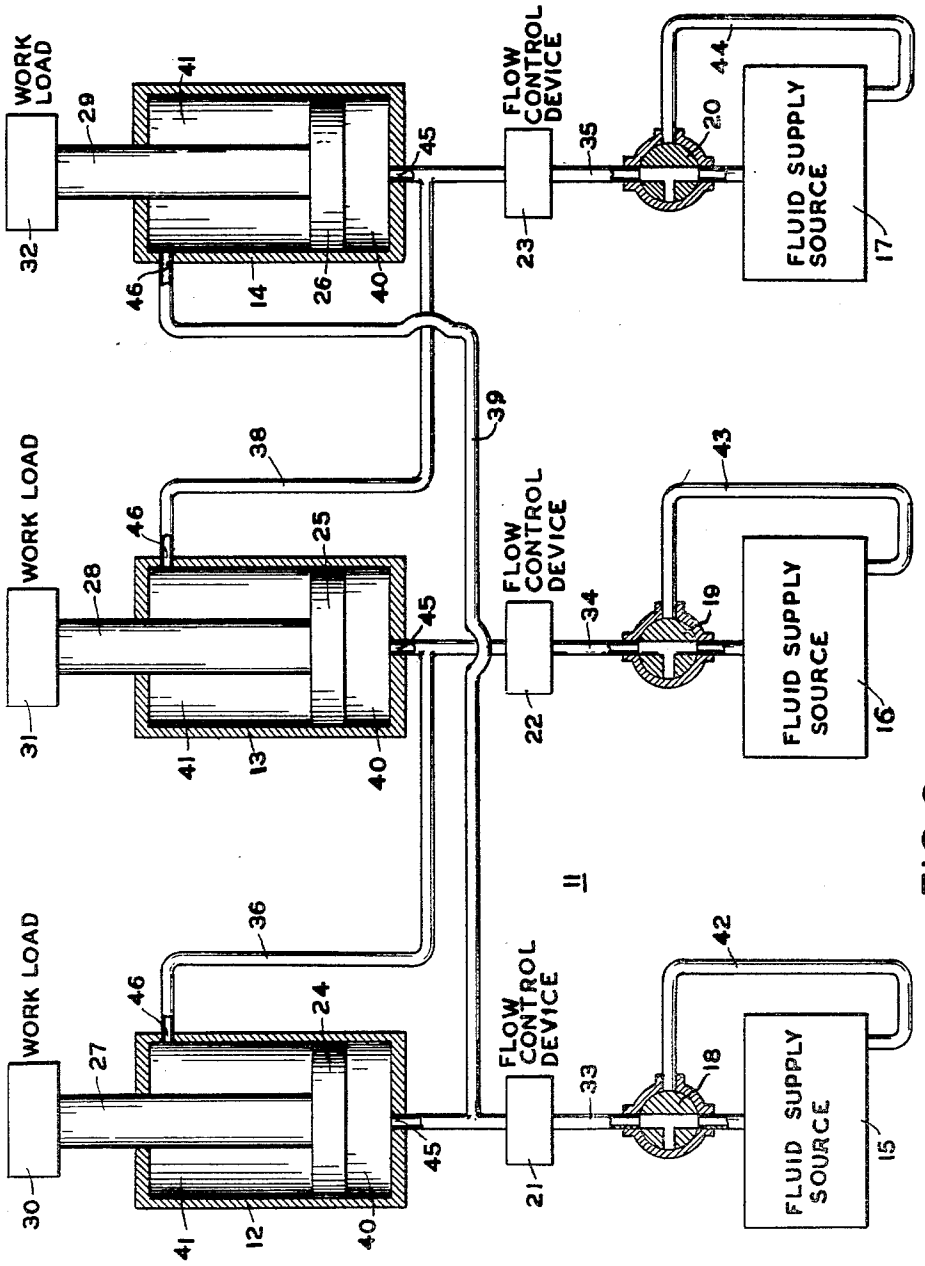


FIG. 2

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2,940,262

HYDRAULIC CROSS-REGENERATIVE CIRCUIT

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13 Claims. (Cl. 60—97)

This invention relates in general to hydraulic control systems and more particularly to a hydraulic cross-regenerative circuit for connecting two or more cylinders together.

It is an object of the invention to provide dual hydraulic cylinders each having a blind end chamber and a rod end chamber, the rod end chamber of each cylinder being connected to the blind end chamber of the other cylinder by any fluid line.

Another object of the invention is to provide three or more hydraulic cylinders each having a blind end chamber and a rod end chamber, with the rod end chamber of each cylinder being connected by a fluid line to the blind end chamber of only one other cylinder and with each blind end chamber being connected by a fluid line to the rod end chamber of only one other cylinder.

Another object of my invention, in a multiple hydraulic cylinder cross-regenerative circuit, is that the difference in cylinder velocities due to dissimilar flows into and out of the hydraulic system is less than it would be in a normal regenerative circuit.

Another object of my invention, in a multiple hydraulic cylinder cross-regenerative circuit, is that the difference in pressure due to dissimilar work loads is less than it would be in a normal regenerative circuit.

Other objects and a better understanding of my invention may be had by referring to the following description and claims taken in conjunction with the accompanying drawings, in which:

Figure 1 shows a cross-regenerative dual cylinder hydraulic circuit in direct relation with a pump, a three-way valve, and a flow control device; and

Figure 2 shows a cross-regenerative hydraulic circuit connecting three hydraulic cylinders together.

With specific reference to Figure 1 of the drawings, a dual cylinder hydraulic cross-regenerative circuit is designated by the reference character **10**. The circuit **10** comprises generally dual hydraulic cylinders **12** and **13** often referred to as reciprocating differential motors, each being supplied with hydraulic fluid under pressure from a fluid supply source **15** and **16** and each being regulated by a three-way valve **18** and **19** and a flow control device **21** and **22**. The three-way valves **18** and **19** regulate the direction of fluid flow and the flow control devices **21** and **22** determine the amount of flow into and out of the cylinders **12** and **13**.

The fluid supply sources **15** and **16** may be standard pumps which pump fluid under pressure to the cylinders **12** and **13**, respectively. Return flow conduits **42** and **43** connected to the fluid supply sources **15** and **16** and to the three-way valves **18** and **19**, respectively, permit the returning fluid to flow back into the fluid supply sources **15** and **16**. The fluid supply source **15** is connected to the cylinder **12** by a conduit **33** and the fluid supply source **16** is connected to the cylinder **13** by a conduit **34**. It is understood that the conduits **33** and **34** may be of any size and of any material available on the market today.

The cylinders **12** and **13** each have pistons **24** and **25**, respectively, mounted therein reciprocable intermediate their ends, which divide the cylinders into blind end chambers **40** and into rod end chambers **41**, respectively. Connected to each piston **24** and **25** are piston rods **27** and **28**, respectively. The piston rods **27** and **28** pass through the rod end chambers **41** of the cylinders **12** and **13** and extend externally thereof and engage movable work loads **30** and **31**, respectively. It is understood that if double rods are employed in each cylinder, the end of a double rod hydraulic cylinder with the smaller rod diameter will be also referred to as the blind end chamber of the cylinder. The movable work loads **30** and **31** may be parts to be moved on modern tool machines and automation equipment. The cylinders **12** and **13** connected by the cross-regenerative circuit **10** may also be used in industry in general for pushing, pulling, lifting, lowering, feeding, transferring, riveting, shearing and counterbalancing.

The blind end chambers **40** of cylinders **12** and **13** have ports **45** therein to permit the passage of fluid therethrough. The rod end chambers **41** of cylinders **12** and **13** also have ports **46** to permit the passage of fluid therethrough. A conduit **37** is connected to port **45** of the blind end chamber **40** of the cylinder **12** and to the port **46** of the rod end chamber **41** of the cylinder **13**. A conduit **36** is connected to the port **45** of the blind end chamber **40** of cylinder **13** and to the port **46** of the rod end chamber **41** of the cylinder **12**.

The dual cylinder hydraulic cross-regenerative circuit **10** has primarily two beneficial functions. The first function of the circuit **10** is to cause the difference in cylinder velocities due to dissimilar fluid flows into or out of the system to be less than it would be in a normal regenerative circuit. The second function of the circuit is to cause the difference in pressures acting on the pistons **24** and **25** due to dissimilar work loads **30** and **31** to be less than it would be in a normal regenerative circuit.

The present invention of the hydraulic cross-regenerative circuit **10** differs from the normal regenerative circuit in that the dual cylinders embodied in the normal regenerative circuit are not cross-connected by conduits but the blind end chamber and the rod end chamber in each cylinder are connected by conduits to each other. Thus, on the upstroke of the piston, the fluid displaced in the rod end chamber will flow back into the blind end chamber of the same cylinder. Thus, dual hydraulic cylinders in a normal regenerative circuit are independent of each other.

One of the functions of the cross-regenerative circuit **10** is to cause the difference in cylinder velocities due to dissimilar flows into and out of the hydraulic system to be less than it would be in the normal regenerative circuit. The dissimilar flows in to or out of the system are mainly caused by differences in the flow control devices **21** and **22**. It is difficult to adjust (or manufacture) one flow control device exactly the same as another to permit exactly the same amount of fluid to flow through both of them. Thus, because it is difficult to adjust (or manufacture) the flow control devices **21** and **22** exactly the same and since cylinder velocity is directly proportional to fluid flow into or out of the system, it is highly desirable to have a circuit that will cause the pistons to move in as perfect synchronism as possible. It is understood that the difference in dissimilar flows, due to the difficulty of adjusting or manufacturing the flow control devices precisely, is very slight. For example, if 10 gallons per minute were required, one flow control device may pass 9.990 gallons per minute and the other flow control device may pass 10.010 gallons per minute. But even this minute difference may cause the pistons in a normal regenerative circuit, in a total travel length of 40 inches, to be off ¼ of an inch or more. In close tolerance work,

this wide tolerance of ¼ of an inch is undesirable. It will be shown that the cross-regenerative circuit **10** will cause the cylinder velocities due to dissimilar flows to be less than they would be in a normal regenerative circuit and in a travel of 40 inches in the present invention, the travel tolerance between the two pistons may be as small as 1/16 of an inch or less.

In the following flow formulas for cross-regenerative circuit, let Q equal the total flow into or out of the blind end of the cylinder; let B equal the cylinder rod chamber area divided by the cylinder blind chamber area; and let Qm equal the controlled rate of flow into or out of the system. It is understood in all the formulas given that the subscript$_1$ represents cylinder **12** and the subscript$_2$ represents cylinder **13**. Thus the flow formulas for cross-regenerative circuits are:

Q_1 equals Qm_1 plus B_2Q_2 (Equation 1, cylinder **12**)
Q_2 equals Qm_2 plus B_1Q_1 (Equation 2, cylinder **13**)

Applying the two equations above mentioned, it is now possible to assign values to the letters in the formulas and prove that the difference in cylinder velocities in the cross-regenerative circuit due to dissimilar flows is less than it would be in the normal regenerative circuit.

With specific reference to Figure 1 of the drawings, the following values are assigned to the different parts shown. In this particular case, the diameters of the cylinders are identical and the diameters of the rods are identical. Accordingly, the overall effect is that the cylinders **12** and **13** are matched. Assume that in cylinder **12**, Qm_1 equals 2 gallons per minute and B_1 equals 5. Further assume that in cylinder **13**, Qm_2 equals 4 gallons per minute and B_2 equals .5.

It is understood that in this particular case for simplicity, the dissimilar flows are 4 gallons per minute and 2 gallons per minute, instead of 9.990 gallons per minute and 10.010 gallons per minute. In actual practice, dissimilar flows from two different flow control devices would never be two gallons per minute unless it was desirable to have the velocity of one piston to be faster than the other. The following is purely a hypothetical case.

With these values substituted in the Equations 1 and 2, the equations become:

Q_1 equals 2 plus $.5(Q_2)$ (Equation 3, cylinder **12**)
Q_2 equals 5 plus $.5(Q_1)$ (Equation 4, cylinder **13**)

The next step is to substitute the value of Equation 4 into Equation 3 and the equation becomes:

Q_1 equals 2 plus $.5(4$ plus $.5Q_1)$ (Equation 5, cylinder **12**)

Removing the brackets, Equation 5 becomes:

Q_1 equals 2 plus 2 plus $.25Q_1$ (Equation 6, cylinder **12**)

Grouping like terms, Equation 6 becomes:

$.75Q_1$ equals 4 (Equation 7, cylinder **12**)

Thus: Q_1 equals 5⅓ gallons per minute. Substitute the value 5⅓ in Equation 4 and the equation becomes:

Q_1 equals 4 plus $.5(5⅓)$ (Equation 8, cylinder **12**)

Removing the brackets and adding, Equation 8 becomes:

Q_2 equals 6⅔ gallons per minute

Using the same figures employed above, it is found that Q_1 in the normal regenerative circuit equals 8 gallons per minute and that Q_2 equals 4 gallons per minute. It is noted that the difference of flow into the blind end chambers of cylinders **12** and **13** in the cross-regenerative circuit is 1⅓ gallons per minute while the difference of flow in the normal regenerative circuit is 4 gallons per minute.

It is well known that cylinder velocity is directly proportional to flow into or out of the blind end chamber

of the cylinder. Thus, in the normal regenerative circuit, the piston in cylinder **13** will move eight units while the piston in cylinder **12** during the same interval of time will have moved only four units, a difference of four units. In the cross-regenerative circuit, the difference in unit travel of the pistons in cylinders **12** and **13** is only one and one-third (1⅓) units. Thus, the pistons in the cross-regenerative circuit will be in closer synchronism than in a normal circuit. It is understood that the units given hereinabove are hypothetical and for illustration only, but the same flow formulas would apply for any values given.

For a cross-regenerative circuit receiving 9.990 gallons per minute into the system at cylinder **12** and receiving 10.010 gallons per minute into the system at cylinder **13**, the fluid flow into the blind end chamber **40** at cylinder **12** will be 19.9933 gallons per minute and the fluid flow into the blind end chamber **40** at cylinder **13** will be 20.0066 gallons per minute. Thus, the difference in fluid flow will be .0133 gallon per minute, while the difference in fluid flow in the normal regenerative circuit will be .04, thus three times as much as in the cross-regenerative circuit **10**.

In actual practice for typical installations, the stroke travel tolerance or variance between the two pistons in the cross-regenerative circuit may be, for example, as small as 1/16 of an inch, while in a normal regenerative circuit, the stroke travel variance under the same hereinabove-mentioned conditions may be, for example, as large as four inches or more. Thus, in the cross-regenerative circuit, the difference in cylinder velocities due to dissimilar flows into and out of the hydraulic system is less than it would be in a normal regenerative circuit.

Another function of the cross-regenerative circuit **10** is to cause the difference in pressure acting on pistons **24** and **25** due to dissimilar work loads **30** and **31** to be less than it would be in a normal regenerative circuit. Assume that the pistons in cylinders **12** and **13** in the normal regenerative circuit are on the upstroke and at a given instant the work load at cylinder **12** is rapidly decreased. The piston **24** would tend to surge forward at that instant due to the pressure acting on a lighter work load of the piston and thus the affected piston **24** would not be synchronous with the other piston **25**. Thus dissimilar or changing work loads, as well as dissimilar flows, tend to cause a difference in cylinder velocities and fluid pressures. Assume that in the cross-regenerative circuit on the upstroke the work load on cylinder **12** is rapidly decreased. Due to the pressure acting on the lighter work load of the affected piston **24**, that piston will surge forward. Since the blind end chambers are connected to the rod end chambers of each cylinder, the pressure acting on one piston affects the pressure acting on the other piston. Thus, when the pressure is changed in one chamber, the pressure will also be changed in the other chamber which is cross-connected thereto. This tendency in the cross-regenerative circuit for the difference in pressure to become smaller in both pistons has a tendency to keep the two pistons in more perfect synchronism and free from a jerking motion. In a typical case, for example, assume that two pistons are on the upstroke and at a given moment the work load on one piston decreases from 2400 pounds to 1200 pounds. At that instant, the affected piston may, for example, surge forward ¼ of an inch. If the pistons are not cross-connected, this change in the work load at one piston will not affect the other piston. In the cross-regenerative circuit, a change in pressure acting at one piston affects the pressure acting on the other piston so that the pistons will keep in closer synchronism than they would be in a normal regenerative circuit.

In the following pressure formulas, let P equal pressure; let W equal the work load or load reaction force, including gravity; let A equal the cylindrical area of the blind end chambers **40**; let C equal the cylindrical area of the rod end chambers **41**.

Thus the pressure formulas for the cross-regenerative circuit are:

W_1 equals A_1P_1 minus C_1P_2 (Equation 9, cylinder **12**)

and

W_2 equals A_2P_2 minus C_2P_1 (Equation 10, cylinder **13**)

Applying the two equations mentioned above, it is now possible to assign values to the letters in the equations and prove that difference in pressures acting on the pistons **24** and **25** due to dissimilar work loads **30** and **31** is less than it would be in a normal regenerative circuit.

Again with specific reference to Figure 1 of the drawings, the following values are assigned to the different parts shown. In this particular case, the diameters of the cylinders and of the rods are identical. Accordingly, the overall effect is that the cylinders **12** and **13** are matched. Assume that in cylinder **12**, W_1 equals 1200 pounds; A_1 equals 5 square inches; and C_1 equals 2.5 square inches. Further assume that in cylinder **13**, W_2 equals 2400 pounds; A_2 equals 5 square inches; and C_2 equals 2.5 square inches. It is understood that the figures given above are hypothetical and for illustration only. With these values substituted in the Equations 9 and 10 for finding pressure in the cross-regenerative circuit, the equation becomes:

1200 equals $5P_1$ minus $2.5P_2$
(Equation 11, cylinder **12**)

2400 equals $5P_2$ minus $2.5P_1$
(Equation 12, cylinder **13**)

Since P_1 and P_2 are the unknowns, Equations 11 and 12 are rewritten for P_1 and P_2 and become:

P_1 equals (1200 plus $2.5P_2$) divided by 5
(Equation 13, cylinder **12**)

P_2 equals (2400 plus $2.5P_2$) divided by 5
(Equation 14, cylinder **13**)

Dividing Equations 13 and 14 by 5, the Equations become:

P_1 equals 240 plus $.5P_2$ (Equation 15, cylinder **12**)
P_2 equals 480 plus $.5P_1$ (Equation 16, cylinder **13**)

Substituting the value for P_2 into Equation 15, the equation becomes:

P_1 equals 240 plus .5(480 plus $.5P_1$)
(Equation 17, cylinder **12**)

Removing the brackets and grouping like terms, the Equation 17 becomes:

$.75P_1$ equals 480 (Equation 18, cylinder **12**)

Thus, P_1 equals 640 p.s.i. on cylinder **12**. Substituting the value 640 in Equation 16:

Thus, P_2 equals 800 p.s.i. on cylinder **13**.

Using the same figures for finding pressure as employed hereinabove, it is found that P_1 in the normal regenerative circuit equals 480 pounds per square inch and that P_2 equals 960 pounds per square inch. It is noted that the difference of pressure acting on the pistons in the cross-regenerative circuit is 160 pounds per square inch, while the difference of pressure acting on the pistons in the normal circuit is 480 pounds per square inch.

It is understood that the hereinabove values for P_1 and P_2 in the cross-regenerative and normal regenerative circuits are hypothetical and serve for illustration purposes only. But it is also understood that the above-mentioned pressure formulas can be used for any values desired.

With specific reference to Figure 2 of the drawings, a multiple cylinder hydraulic cross-regenerative circuit is designated by the reference character **11**. The circuit **11** comprises generally three hydraulic cylinders **12**, **13** and **14**, each being supplied with hydraulic fluid under pressure from a fluid supply source **15**, **16** and **17** and each being regulated by a three-way valve **18**, **19** and **20** and a flow control device **21**, **22** and **23**. The three-way valves **18**, **19** and **20** and the flow control devices **21**, **22** and **23** have the same function as in the dual cylinder hydraulic cross-regenerative circuit **10**. The fluid supply sources **15**, **16** and **17** may be standard pumps and of the type described hereinabove and employed in the circuit shown in Figure 1. The fluid supply sources **15**, **16** and **17** are connected to the cylinders **12**, **13** and **14** by means of conduits **33**, **34** and **35**, respectively, and the conduits may be of the type described hereinabove.

The cylinder **14** is the same type as cylinders **12** and **13** shown in Figure 1 and described hereinabove. Cylinder **14** has a piston **26** mounted therein reciprocable intermediate its end, which divides the cylinder into the blind end chamber **40** and the rod end chamber **41**. Connected to the piston **26** is a piston rod **29** which passes through the rod end chamber **41** and extends externally thereof and engages a movable work load **32**. It is understood that the work load **32** may be the same as the loads **30** and **31**.

The blind end chamber **40** and the rod end chamber **41** of the cylinder **14** have ports **45** and **46**, respectively, to permit the passage of fluid therethrough. As shown specifically in Figure 2 of the drawings, the conduit **36** is connected to port **45** of the blind end chamber **40** of cylinder **13** and to port **46** of the rod end chamber **41** of cylinder **12**. A conduit **38** is connected to port **45** of the blind end chamber **40** of cylinder **14** and to port **46** of the rod end chamber **41** of cylinder **13**. A conduit **39** is connected to port **45** of the blind end chamber **40** of cylinder **12** and to port **46** of the rod end chamber **41** of cylinder **14**. Thus, the rod end chamber **41** of each cylinder is connected by a conduit or fluid line to the blind end chamber **40** of only one other cylinder and the blind end chamber **40** is connected by a fluid line to the rod end chamber **41** of only one other cylinder.

The multiple cylinder hydraulic cross-regenerative circuit **11** has primarily the same functions as the dual cylinder hydraulic cross-regenerative circuit **10**, which are described fully hereinabove. It is understood that more than three cylinders may be employed in the multiple cylinder hydraulic cross-regenerative circuit **11**. Thus, any number of hydraulic cylinders may be employed in the circuit **11**, as long as they are connected in the manner described.

The pistons upon completion of their power stroke may be returned to the beginning of a new stroke by the work actuating devices or by any external force. The return travel of the pistons would be controlled by synchronization of the system, the same as they are controlled on the power stroke. The flow control device and the cross-connected pistons would operate the same on the return stroke but in a reverse direction. Also, the pistons may be returned to the beginning of a new stroke by additional valving by drawing out the fluid in the cylinder chambers through external fluid circuits.

It is understood that the cylinders may be connected to a single fluid source, with a flow control device connected respectively in fluid circuit relation with each cylinder. In some installations, a single fluid source and a single flow control device connected respectively to all the cylinders may be used. Also in some installations the flow control device may be entirely eliminated in the case of substantially uniform loading.

Although this invention has been described in its preferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and scope of the invention as hereinafter claimed.

What is claimed is:

1. A hydraulic cross-regenerative circuit adapted to be connected to a fluid supply source comprising, in combination, first and second cylinders, said first cylinder having a first piston mounted therein reciprocable intermediate its ends, said first piston having first and second piston end areas dividing said first cylinder into first and second chambers, a first piston rod connected to said first piston and extending from said second piston end area thereof, said first piston rod passing through said second chamber in said first cylinder and extending externally thereof for performing work, said second cylinder having a second piston mounted therein reciprocable intermediate its ends, said second piston having first and second piston end areas dividing said second cylinder into first and second chambers, a second piston rod connected to said second piston and extending from said second piston end area thereof, said second piston rod passing through said second chamber in said second cylinder and extending externally thereof for performing work, said first piston end area of said first piston being larger than said second piston area thereof, said first piston end area of said second piston being larger than said second piston area thereof, said first and second chambers in said first and second cylinders having port means therein permitting the passage of fluid therethrough, first conduit means connecting said port means in said first chamber of said first cylinder with said fluid supply source, second conduit means connecting said port means in said first chamber of said second cylinder with said fluid supply source, third conduit means connecting said port means in said first chamber of said first cylinder with said port means in said second chamber of said second cylinder, fourth conduit means connecting said port means in said first chamber of said second cylinder with said port means in said second chamber of said first cylinder.

2. A hydraulic cross-regenerative circuit adapted to be connected to a fluid supply source comprising in combination, first and second cylinders, said first cylinder having piston means mounted therein reciprocable intermediate its ends and dividing said first cylinder into first and second chambers, said second cylinder having piston means mounted therein reciprocable intermediate its ends and dividing said second cylinder into first and second chambers, said piston means each having first and second end areas, said first end area exposed to said first chamber and said second end area exposed to said second chamber, means connected to said second end area of each of said piston means and extending externally of said respective cylinders for performing work, said second end area of said piston means being smaller than said first end area of said piston means, said first and second chambers in said first and second cylinders having port means therein permitting the passage of fluid therethrough, first conduit means connecting said port means in said first chamber of said first cylinder with said fluid supply source, second conduit means connecting said port means in said first chamber of said second cylinder with said fluid supply source, third conduit means connecting said port means in said first chamber of said first cylinder with said port means in said second chamber of said second cylinder, fourth conduit means connecting said port means in said first chamber of said second cylinder with said port means in said second chamber of said first cylinder.

3. A hydraulic cross-regenerative circuit adapted to be connected to a fluid supply source comprising in combination, first and second cylinders, said first cylinder having piston means mounted therein reciprocable intermediate its ends and dividing said first cylinder into first and second chambers, said second cylinder having piston means mounted therein reciprocable intermediate its ends and dividing said second cylinder into first and second chambers, said piston means each having first and second end areas, said first end area exposed to said first chamber and said second end area exposed to said second chamber, one of said end areas of said piston means being smaller than the other said end area of said piston means, means connected to each of said piston means and extending externally of said respective cylinders for performing work, said first and second chambers in said first and second cylinders having port means therein permitting the passage of fluid therethrough, first conduit means connecting said port means in said first chamber of said first cylinder with said fluid supply source, second conduit means connecting said port means in said first chamber of said second cylinder with said fluid supply source, third conduit means connecting said port means in said first chamber of said first cylinder with said port means in said second chamber of said second cylinder, fourth conduit means connecting said port means in said first chamber of said second cylinder with said port means in said second chamber of said first cylinder.

4. A hydraulic cross-regenerative circuit adapted to be connected to a fluid supply source comprising in combination, first and second cylinders, said first cylinder having a piston mounted therein reciprocable intermediate its end and dividing said first cylinder into first and second chambers, said second cylinder having a piston mounted therein reciprocable intermediate its ends and dividing said second cylinder into first and second chambers, said piston means each having first and second end areas, said first end area exposed to said first chamber and said second end area exposed to said second chamber, a piston rod connected to said second end area of each of said pistons and passing through each of said second chambers in said first and second cylinders and extending externally thereof for performing work, said second end area of said piston means being smaller than said first end area of said piston means, said first and second chambers in said first and second cylinders having port means therein permitting the passage of fluid therethrough, first conduit means connecting said port means in said first chamber of said first cylinder with said fluid supply source, second conduit means connecting said port means in said first chamber of said second cylinder with said fluid supply source, third conduit means connecting said port means in said first chamber of said first cylinder with said port means in said second chamber of said second cylinder, fourth conduit means connecting said port means in said first chamber of said second cylinder with said port means in said second chamber of said first cylinder, first flow control means connected in fluid circuit relation with said first conduit means and intermediate said fluid source and said first chamber of said first cylinder, second flow control means connected in fluid circuit relation with said second conduit means and intermediate said fluid supply source and said first chamber of said second cylinder.

5. A hydraulic cross-regenerative circuit adapted to be connected to a fluid supply source comprising in combination, first and second cylinders, said first cylinder having piston means mounted therein reciprocable intermediate its ends and dividing said first cylinder into first and second chambers, said second cylinder having piston means mounted therein reciprocable intermediate its ends and dividing said second cylinder into first and second chambers, said piston means each having first and second end areas, said first end area exposed to said first chamber and said second end area exposed to said second chamber, means connected to said second end area of each of said piston means and extending externally of said respective cylinders for performing work, said second end area of said piston means being smaller than said first end area of said piston means, said first and second chambers in said first and second cylinders having port means therein permitting the passage of fluid therethrough, first conduit means connecting said port means in said first chamber of said first cylinder with said fluid supply source, second conduit means connecting said port means in said first chamber of said second cylinder with said fluid supply source, third conduit means connecting said port means in said first chamber of said first cylinder with said port

means in said second chamber of said second cylinder, fourth conduit means connecting said port in said first chamber of said second cylinder with said port in said second chamber of said first cylinder, first flow control means connected in fluid circuit relation with said first conduit means and intermediate said fluid source and said first chamber of said first cylinder, second flow control means connected in fluid circuit relation with said second conduit means and intermediate said fluid supply source and said first chamber of said second cylinder.

6. A hydraulic cross-regenerative circuit adapted to be connected to a fluid supply source comprising in combination, first and second cylinders, said first cylinder having piston means mounted therein reciprocable intermediate its ends and dividing said first cylinder into first and second chambers, said second cylinder having piston means mounted therein reciprocable intermediate its ends and dividing said second cylinder into first and second chambers, said piston means having first and second end areas, said first end area exposed to said first chamber and said second end area exposed to said second chamber, one of said end areas of said piston means being smaller than the other said end area of said piston means, means connected to each of said piston means and extending externally of said respective cylinders for performing work, said first and second chambers in said first and second cylinders having port means therein permitting the passage of fluid therethrough, first conduit means connecting said port means in said first chamber of said first cylinder with said fluid supply source, second conduit means connecting said port means in said first chamber of said second cylinder with said fluid supply source, third conduit means connecting said port means in said first chamber of said first cylinder with said port means in said second chamber of said second cylinder, fourth conduit means connecting said port means in said first chamber of said second cylinder with said port means in said second chamber of said first cylinder, first flow control means connected in fluid circuit relation with said first conduit means and intermediate said fluid source and said first chamber of said first cylinder, second flow control means connected in fluid circuit relation with said second conduit means and intermediate said fluid supply source and said first chamber of said second cylinder.

7. A hydraulic cross-regenerative circuit adapted to be connected to a fluid supply source comprising in combination, first, second and third cylinders each having piston means mounted therein reciprocable intermediate its ends and dividing each of said cylinders into first and second chambers, said piston means each having first and second end areas, and first end area exposed to said first chamber and said second end area exposed to said second chamber, rod means connected to said second end area of each of said piston means and passing respectively through said chambers in said first, second and third cylinders and extending externally thereof for performing work, said second end area of said piston means being smaller than said first end area of said piston means, said first and second chambers in said first, second and third cylinders having port means therein permitting the passage of fluid therethrough, first conduit means connecting said port means in said first chamber of said first cylinder with said fluid supply source, second conduit means connecting said port means in said first chamber of said second cylinder with said fluid supply source, third conduit means connecting said port means in said first chamber of said third cylinder with said fluid supply source, fourth conduit means connecting said port means in said first chamber of said second cylinder with said port means in said second chamber of said first cylinder, first conduit means connecting said port means in said first chamber of said third cylinder with said port means in said second chamber of said second cylinder, sixth conduit means connecting said port means in said first chamber of said first cylinder with said port means in said second chamber of said third cylinder.

8. A hydraulic cross-regenerative circuit adapted to be connected to a fluid supply source comprising in combination, first, second and third cylinders each having piston means mounted therein reciprocable intermediate its ends and dividing each of said cylinders into first and second chambers, said piston means each having first and second end areas, said first end area exposed to said first chamber and said second end area exposed to said second chamber, rod means connected to said second end area of each of said piston means and passing respectively through said chambers in said first, second and third cylinders and extending externally thereof for performing work, said second end area of said piston means being smaller than said first end area of said piston means, said first and second chambers in said first, second and third cylinders having port means therein permitting the passage of fluid therethrough, first conduit means connecting said port means in said first chamber of said first cylinder with said fluid supply source, second conduit means connecting said port means in said first chamber of said second cylinder with said fluid supply source, third conduit means connecting said port means in said first chamber of said third cylinder with said fluid supply source, fourth conduit means connecting said port means in said first chamber of said second cylinder with said port means in said second chamber of said first cylinder, fifth conduit means connecting said port means in said first chamber of said third cylinder with said port means in said second chamber of said second cylinder, sixth conduit means connecting said port means in said first chamber of said first cylinder with said port means in said second chamber of said third cylinder, first flow control means connected in fluid circuit relation with said first conduit means and intermediate said fluid source and said first chamber of said first cylinder, second flow control means connected in fluid circuit relation with said second conduit means and intermediate said fluid supply source and said first chamber of said second cylinder, third flow control means connected in fluid circuit relation with said third conduit means and intermediate said fluid supply source and said first chamber of said third cylinder.

9. A hydraulic cross-regenerative circuit adapted to be connected to a fluid supply source comprising in combination, a plurality of cylinders each having piston means mounted therein reciprocable intermediate its ends and dividing said cylinders into first and second chambers, said piston means each having first and second end areas, said first end areas exposed to said first chamber and said second end area exposed to said second chamber, means connected to said second end area of each of said pistons and extending externally of said respective cylinders for performing work, said second end area of said piston means being smaller than said first end area of said piston means, said first and second chambers in said cylinders having port means therein permitting the passage of fluid therethrough, conduit means connecting said port means in said first chamber of each said cylinders with said fluid supply source, conduit means interconnecting said port means in said second chamber of each of said cylinders respectively with said port means in said first chamber of each of said cylinders.

10. A hydraulic cross-regenerative circuit adapted to be connected to a fluid supply source comprising in combination, a plurality of cylinders each having piston means mounted therein reciprocable intermediate its ends and dividing said cylinders into first and second chambers, said piston means each having first and second end areas, said first end area exposed to said first chamber and said second end area exposed to said second chamber, means connected to said second end area of each of said pistons and extending externally of said respective cylinders for performing work, said second end area of said piston means being smaller than said first end area of said piston means, said first and second chambers in said cylinders having port means therein permitting the passage of

fluid therethrough, first conduit means connecting said port means in said first chamber of each of said cylinders with said fluid supply source, second conduit means interconnecting said port means in said second chamber of each of said cylinders respectively with said port means in said first chamber of each of said cylinders, a plurality of flow control means respectively connected in fluid circuit relation with said first conduit means and intermediate said fluid supply source and said respective first chamber of said plurality of cylinders.

11. A hydraulic cross-regenerative circuit adapted to be connected to a fluid supply source comprising in combination, a plurality of cylinders each having piston means mounted therein reciprocable intermediate its ends and dividing said cylinders into first and second chambers, said piston means each having first and second end areas, said first end area exposed to said first chamber and said second end area exposed to said second chamber, means connected to said second end area of each of said pistons and extending externally of said respective cylinders for performing work, said second end area of said piston means being smaller than said first end area of said piston means, said first and second chambers in said cylinders having port means therein permitting the passage of fluid therethrough, first conduit means connecting said port means in said first chamber of each of said cylinders with said fluid supply source, second conduit means interconnecting said port means in said second chamber of each of said cylinders respectively with said port means in said first chamber of each of said cylinders, flow control means connected in fluid circuit relation with said first conduit means and intermediate said fluid supply source and said respective first chamber of said plurality of cylinders.

12. A hydraulic cross-regenerative circuit adapted to be connected to a fluid supply source comprising in combination, first and second cylinder means, said first cylinder means having piston means mounted therein and defining first and second chambers, said second cylinder means having piston means mounted therein and defining first and second chambers, said piston means each having first and second end areas, said first end area exposed to said first chamber and said second end area exposed to said second chamber, means connected to said second end area of each of said piston means and extending externally of said respective cylinder means for performing work, said second end area of said piston means being smaller than said first end area of said piston means, said first and second chambers in said first and second cylinder means having port means therein permitting the passage of fluid therethrough, first conduit means connecting said port means in said first chamber of said first cylinder means with said fluid supply source, second conduit means connecting said port means in said first chamber of said second cylinder means with said fluid supply source, third conduit means connecting said port means in said first chamber of said first cylinder means with said port means in said second chamber of said second cylinder means, fourth conduit means connecting said port means in said first chamber of said second cylinder means with said port means in said second chamber of said first cylinder means.

13. A hydraulic cross-regenerative circuit adapted to be connected to a fluid supply source comprising in combination, first and second cylinder means, said first cylinder means having piston means mounted therein and defining first and second chambers, said second cylinder means having piston means mounted therein and defining first and second chambers, said piston means each having first and second end areas, said first end area exposed to said first chamber and said second end area exposed to said second chamber, means connected to said second end area of each of said piston means and extending externally of said respective cylinder means for performing work, said second end area of said piston means being smaller than said first end area of said piston means, said first and second chambers in said first and second cylinder means having port means therein means permitting the passage of fluid therethrough, first conduit means connecting said port means in said first chamber of said first cylinder means with said fluid supply source, second conduit means connecting said port means in said first chamber of said second cylinder means with said fluid supply source, third conduit means connecting said port means in said first chamber of said first cylinder means with said port means in said second chamber of said second cylinder means, fourth conduit means connecting said port means in said first chamber of said second cylinder means with said port means in said second chamber of said first cylinder means, first flow control means connected in fluid circuit relation with said first conduit means and intermediate said fluid source and said first chamber of said first cylinder means, second flow conrtol means connected in fluid circuit relation with said second conduit means and intermediate said fluid supply source and said first chamber of said second cylinder means.

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