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OFFSET VALVE BORE IN A RECIPROCATING PUMP**Technical Field**

5 [0001] An arrangement is disclosed whereby a valve bore is offset from a plunger bore in a fluid end of a reciprocating pump to relieve stress.

Background of the Disclosure

10 [0002] In oil field operations, reciprocating pumps are used for various purposes. Reciprocating pumps are used for operations such as cementing, acidizing, or fracturing of a subterranean well. These reciprocating pumps run for relatively short periods of time, but they operate on a frequent basis and oftentimes at extremely high pressures. A reciprocating pump is mounted to a truck or a skid for transport to various well sites and must be of appropriate size and weight for road and highway regulations.

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[0003] Reciprocating pumps or positive displacement pumps for oil field operations deliver a fluid or slurry, which may carry solid particles (for example, a sand proppant), at pressures up to 20,000 psi to the wellbore. A known pump for oilfield operations includes a power end driving more than one plunger reciprocally in a corresponding fluid end or pump chamber. The fluid end may comprise three or five plunger bores arranged transversely across a fluid head, and each plunger bore may be intersected by suction and discharge valve bores. In a known reciprocating pump, the axis of each plunger bore intersects perpendicularly with a common axis of the suction and discharge valve bores.

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[0004] In a mode of operating a known three plunger bore reciprocating pump at high fluid pressures (for example, around or greater than 20,000 psi), a maximum pressure and thus stress can occur within a given pump chamber as the plunger moves longitudinally in the fluid end towards top dead center (TDC), compressing the fluid therein. One of the other pump chambers will be in discharge and thus at a very low pressure, and the other pump chamber will have started to compress the fluid therein.

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[0005] It has been discovered that, in a given pump chamber, the areas of highest stress occur at the intersection of each plunger bore with its suction and discharge valve bores as the plunger moves to TDC. The occurrence of high stress at these areas can shorten the life of the fluid end.

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[0006] JP 2000-170643 is directed to a multiple reciprocating pump having a small size. The pump has three piston bores in which the pistons reciprocate but, so that a compact pump configuration can be provided, the axis of each suction valve bore is arranged perpendicularly to its respective discharge valve bore (that is, so that there is a laterally directed discharge from the fluid end).

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[0007] JP 2000-170643 also teaches that a limit as to the volume of fluid that can be pumped by a small reciprocating pump is the size of suction and discharge valve bores. Contrary to the embodiments disclosed herein, the teaching of JP 2000-170643 is not concerned with reducing stresses arising at the intersection of piston, suction and discharge bores. Rather, JP 2000-170643 teaches moving the axes of each of the outside suction and discharge valve bores outwardly with respect to their plunger bore axis to enable the volume of each of the suction and discharge valve bores to be increased. Thus, with an increased pump speed, an increased volumetric flow can be achieved with a pump that still has a similar overall dimensional profile. In addition, JP 2000-170643 teaches that the valve bores are moved outwardly without increasing the amount of material between the suction and discharge bores. This is because the reconfiguration of the pump in JP 2000-170643 is not concerned with reducing stresses within the pump in use.

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Summary

[0008] In a first aspect there is disclosed a fluid end for a multiple reciprocating pump assembly. The multiple reciprocating pump assembly may, for example, comprise three or five plunger bores, and may find application in oilfield operations and/or may operate with fluids at high pressures (for example as high as 20,000 psi or greater).

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[0009] When the fluid end comprises at least three plunger bores (for example, three or five plunger bores), each can receive a reciprocating plunger, and each can have a plunger bore axis. The plunger bores can be arranged across the fluid head to define a central plunger bore and lateral plunger bores located on either side of the central plunger bore (for example, one or two lateral plunger bores located on either side of the central plunger bore to define a fluid end with three or five plunger bores respectively).

[0010] At least three respective suction valve bores (for example, three or five suction valve bores) can be provided for and be in fluid communication with the plunger bores. Each suction valve bore can receive a suction valve and have a suction valve bore axis.

[0011] At least three respective discharge valve bores (for example, three or five discharge valve bores) can be provided for and be in fluid communication with the plunger bores. Each discharge valve bore can receive a discharge valve and have a discharge valve bore axis.

[0012] In accordance with the first aspect, at least one of the axes of the suction and discharge valve bores, for at least one of the lateral plunger bores, is inwardly offset in the fluid end from its respective plunger bore axis.

[0013] It has been surprisingly discovered that this inward offsetting can reduce stress that would otherwise occur at the intersection of each plunger bore with its suction or discharge valve bores as the plunger moves to TDC. The reduction of stress can increase the useful operating life of the fluid end.

[0014] In certain embodiments, at least one of the axes of at least one of the suction and discharge valve bores for each of the lateral plunger bores may be inwardly offset. For example, for the lateral plunger bores, the at least one offset axis may be inwardly offset to the same extent as the other at least one offset axis.

[0015] In certain embodiments, the axes of both the suction and discharge valve bores may be inwardly offset for at least one of the lateral plunger bores. For example, the

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axes of both the suction and discharge valve bores are inwardly offset to the same extent.

5 [0016] In certain embodiments, for each of the plunger bores, the suction valve bore may oppose the discharge valve bore. This arrangement is easier to manufacture, maintain and service than, for example, arrangements in which the axis of each suction valve bore is perpendicular to the discharge valve bore. In addition, the opposing bore arrangement may induce less stress in the fluid end in use than, for example, a perpendicular bore arrangement.

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[0017] In certain embodiments for each of the plunger bores, the axes of the suction and discharge valve bores may be aligned, for even greater ease of manufacture, maintenance and service. In certain embodiments, the at least one axis may be inwardly offset in an amount ranging from about 10% to about 60% of the diameter of the
15 plunger bore. In certain other embodiments, the offset axis may be inwardly offset in an amount ranging from about 20% to about 50%, or from about 30% to about 40%, of the diameter of the plunger bore.

[0018] In other certain embodiments, the at least one axis may be inwardly offset in an
20 amount ranging from about 0.5 to about 2.5 inches. In certain other embodiments, the offset axis may be offset in an amount ranging from about 1.5 to 2.5 inches. These dimensions may represent an optimal range for many bore diameters of fluid end configurations employed in fracking pumps in oilfield and related applications.

25 [0019] Other aspects, features, and advantages will become apparent from the following detailed description when taken in conjunction with the accompanying drawings, which are a part of this disclosure and which illustrate, by way of example, principles of the fluid end as disclosed herein.

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Description of the Figures

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[0020] Notwithstanding any other forms which may fall within the scope of the fluid end as set forth in the Summary, specific embodiments of the fluid end and reciprocating pump will now be described, by way of example only, with reference to the accompanying drawings.

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[0021] In the Description of the Figures and in the Detailed Description of Specific Embodiments, a pump that comprises three plunger, suction and discharge bores is hereafter referred to as a “triplex”, and a pump that comprises five plunger, suction and discharge bores is hereafter referred to as a “quint”, being an abbreviation of “quintuplex”.

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In the drawings:

[0022] Figures 1A and 1B illustrate, in sectional and perspective views, an embodiment of a reciprocating pump. Figure 1A may depict either a triplex or quint, although Figure 1B specifically depicts a triplex.

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[0023] Figure 2 schematically depicts a first embodiment of a triplex, being a partial section of Figure 1A taken on the line 2-2, to illustrate both lateral (or outside) valve bore pairs being offset inwardly from their respective plunger bores.

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[0024] Figure 3 is an underside schematic view of the section of Figure 2 to show a bolt pattern on a fluid end of a cylinder.

[0025] Figure 4 is a similar view of the triplex to Figure 2, but illustrates just one of the lateral (or outside) valve bore pairs being offset inwardly from its respective plunger bore.

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[0026] Figure 5 schematically depicts another embodiment of a triplex but using a partial section similar to Figure 2 to illustrate one of the lateral valve bores being inwardly offset to its respective plunger bore, as well as the central valve bore being offset in a similar direction to its respective plunger bores.

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[0027] Figure 6 is an underside schematic view of the section of Figure 5 to show a bolt pattern on a fluid end of a cylinder.

5 [0028] Figure 7 schematically depicts another embodiment of a triplex using a partial section similar to Figure 2, and wherein just the lateral discharge valve bores are inwardly offset from their respective plunger bores, and not the suction valve bores.

10 [0029] Figure 8 schematically depicts another embodiment of a triplex using a partial section similar to Figure 2, and wherein just the lateral suction valve bores are inwardly offset from their respective plunger bores, and not the discharge valve bores.

15 [0030] Figure 9 schematically depicts a first embodiment of a quint, being a partial section of Figure 1A taken on the line 2-2, to illustrate the two lateral valve bore pairs on either side of the central valve bore pair being offset inwardly from their respective plunger bores.

20 [0031] Figure 10 is an underside schematic view of the section of Figure 9 to show a bolt pattern on a fluid end of a cylinder.

[0032] Figure 11 is a similar view of the quint of Figure 9, but illustrates just the outermost lateral valve bore pairs being offset inwardly from their respective plunger bore.

25 [0033] Figure 12 is a similar view of the quint of Figure 11, but illustrates just one of the outermost lateral valve bore pairs being offset inwardly from its respective plunger bore.

30 [0034] Figure 13 is a similar view of the quint of Figure 9, but illustrates just the innermost lateral valve bore pairs being offset inwardly from their respective plunger bore.

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[0035] Figure 14 is a similar view of the quint of Figure 13, but illustrates just one of the innermost lateral valve bore pairs being offset inwardly from its respective plunger bore.

5 [0036] Figures 15 and 16 schematically depict side sectional elevations as generated by finite element analysis (FEA), and taken from opposite sides, through a triplex fluid end, to illustrate where maximum stress, as indicated by FEA, occurs for the intersection of a plunger bore with the suction and discharge valve bores; with Figure 15 showing no offset and Figure 16 showing 2 inches inward offset.

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[0037] Figure 17 is a data point graph that plot Von Mises yield criterion (that is, for the maximum stress, in psi, as determined by FEA) against the amount of valve bore offset (in inches) for a single (mono) fluid end and valve bore inward offset for a triplex fluid end.

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[0038] Figure 18 is a bar graph that plots Von Mises yield criterion (that is, for the maximum stress, in psi, as determined by FEA) against different amounts of valve bore offset (in inches) for a single (mono) fluid end and a triplex fluid end.

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Detailed Description of Specific Embodiments

[0039] Referring to Figures 1A and 1B, an embodiment of a reciprocating pump 12 housed within a crankshaft housing 13 is shown. The crankshaft housing 13 may comprise a majority of the outer surface of reciprocating pump 12. Stay rods 14 connect the crankshaft housing 13 (the so-called “power end”) to a fluid end 15. When the pump is to be used at high pressures (for instance, in the vicinity of 20,000 psi or greater), up to four stay rods can be employed for each plunger of the multiple reciprocating pump. The stay rods may optionally be enclosed in a housing.

30 [0040] The pump 12 is a triplex having a set of three cylinders 16, each including a respective plunger bore 17. The three (or, in the case of a quint, five) cylinders/plunger bores can be arranged transversely across the fluid end 15. A plunger 35 reciprocates in

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a respective plunger bore 17 and, in Figure 1A, the plunger 35 is shown fully extended at its top dead centre position. In the embodiment depicted, fluid is only pumped at one side 51 of the plunger 35, therefore the reciprocating pump 12 is a single-acting reciprocating pump.

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[0041] Each plunger bore 17 is in communication with a fluid inlet or suction manifold 19 and a fluid outlet side 20 in communication with a pump outlet 21 (Figure 1B). A suction cover plate 22 for each cylinder 16 and plunger bore 17 is mounted to the fluid end 15 at a location that opposes the plunger bore 17. The pump 12 can be free-standing on the ground, can be mounted to a trailer that can be towed between operational sites, or mounted to a skid such as for offshore operations.

[0042] A crankshaft housing 13 encloses a crankshaft 25, which can be mechanically connected to a motor (not shown). The motor rotates the crankshaft 25 in order to drive the reciprocating pump 12. In one embodiment, the crankshaft 25 is cammed so that fluid is pumped from each cylinder 16 at alternating times. As is readily appreciable by those skilled in the art, alternating the cycles of pumping fluid from each of the cylinders 16 helps minimize the primary, secondary, and tertiary (et al.) forces associated with the pumping action.

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[0043] A gear 24 is mechanically connected to the crankshaft 25, with the crankshaft 25 being rotated by the motor (not shown) through gears 26 and 24. A crank pin 28 attaches to the main shaft 23, shown substantially parallel to axis A_X of the crankshaft 25. A connector rod 27 is connected to the crankshaft 25 at one end. The other end of connector rod 27 is secured by a bushing to a crosshead or gudgeon pin 31, which pivots within a crosshead 29 in housing 30 as the crankshaft 25 rotates at the one end of the connector rod 27. The pin 31 also functions to hold the connector rod 27 longitudinally relative to the crosshead 29. A pony rod 33 extends from the crosshead 29 in a longitudinally opposite direction from the crankshaft 25. The connector rod 27 and the crosshead 29 convert rotational movement of the crankshaft 25 into longitudinal movement of the pony rod 33.

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[0044] The plunger 35 is connected to the pony rod 33 for pumping the fluid passing through each cylinder 16. Each cylinder 16 includes an interior or cylinder chamber 39, which is where the plunger 35 compresses the fluid being pumped by reciprocating pump 12. The cylinder 16 also includes an inlet (or suction) valve 41 and an outlet (or
5 discharge) valve 43. Usually the inlet and outlet valves 41, 43 are arranged in an opposed relationship in cylinder 16 and may, for example, lie on a common axis.

[0045] The valves 41 and 43 are usually spring-loaded and are actuated by a predetermined differential pressure. The inlet (suction) valve 41 actuates to control
10 fluid flow from the fluid inlet 19 into the cylinder chamber 39, and the outlet (discharge) valve 43 actuates to control fluid flow from the cylinder chamber 39 to the outlet side 20 and thence to the pump outlet 21. Depending on the size of the pump 12, the plunger 35 may be one of a plurality of plungers, for example, three or five plungers may be utilized.

15 [0046] The plunger 35 reciprocates, or moves longitudinally, toward and away from the chamber 39, as the crankshaft 25 rotates. As the plunger 35 moves longitudinally away from the cylinder chamber 39, the pressure of the fluid inside the chamber 39 decreases, creating a differential pressure across the inlet valve 41, which actuates the valve 41
20 and allows the fluid to enter the cylinder chamber 39 from the fluid inlet 19. The fluid continues to enter the cylinder chamber 39 as the plunger 35 continues to move longitudinally away from the cylinder 17 until the pressure difference between the fluid inside the chamber 39 and the fluid in the fluid inlet 19 is small enough for the inlet valve 41 to actuate to its closed position.

25 [0047] As the plunger 35 begins to move longitudinally into the cylinder 16, the pressure on the fluid inside of the cylinder chamber 39 begins to increase. Fluid pressure inside the cylinder chamber 39 continues to increase as the plunger 35 approaches the chamber 39 until the differential pressure across the outlet valve 43 is
30 large enough to actuate the valve 43 and allow the fluid to exit the chamber 39 through the fluid outlet 21.

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[0048] The inlet valve 41 is located within a suction valve bore 59 and the outlet valve 43 is located within a discharge valve bore 57. In the embodiment depicted, both valve bores 57, 59 are in communication with, and extend orthogonally to the plunger bore 17. The valve bores 57, 59 as shown are also co-axial (that is, lying on a common axis, or with parallel axes), but they may be offset relative to each other as described below.

[0049] It should be noted that the opposing arrangement of the valve bores 57, 59 depicted in Figure 1 is easier to manufacture (for example, by casting and machining), and is easier to maintain and easier to service than, for example, a perpendicular arrangement of the valve bores (that is, where the axes of the bores are perpendicular). In the opposing bores arrangement, the bores can be easily accessed, packed, unpacked and serviced from under and above the fluid end, without interfering with the inlet and outlet manifolds.

[0050] In addition, it is understood that, where stress reduction in the fluid end is desirable, the opposing arrangement of the valve bores 57, 59 may induce less stress in the fluid end, especially at high operating pressures of 20,000 psi or greater, when compared with a perpendicular or other angled bore arrangement.

[0051] Referring now to Figure 2, a partial sectional view of the fluid end 15 of the pump 12 taken on the line 2-2 of Figure 1A is schematically depicted. In the embodiment of Figures 2 and 3, the pump 12 is a triplex having three plunger bores 17 corresponding to three cylinder bores. However, as described hereafter with reference to Figures 9 to 14, the pump can have a different number of cylinders and plunger bores, such as five. For a symmetric triplex fluid end, a central bore of the three plunger bores lies on a central axis of the fluid end, with the other two plunger bores arranged evenly on either side of the central plunger bore. Inward offset may be with respect to a central axis of the fluid end.

[0052] In the embodiment of Figures 2 and 3 each of the three plunger bores 17 is indicated schematically with the reference numeral 61 (that is, 61a, 61b and 61c); each of the three suction valve bores is indicated schematically with the reference numeral

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59 (that is, 59a, 59b and 59c); and each of the three discharge valve bores is indicated schematically with the reference numeral 57 (that is, 57a, 57b and 57c). Similarly, the axis of each plunger bore 61 is indicated schematically with the reference numeral 65 (that is, 65a, 65b and 65c). Also, the common axis of each of the valve bores 59, 57 is indicated schematically with the reference numeral 63 (that is, 63a, 63b and 63c). This nomenclature will also be used hereafter with reference to each of the different triplex fluid end embodiments described herein in Figures 2 to 8.

[0053] It has been discovered that the highest point of stress concentration in pump 12 occurs at the intersection of a plunger bore with the suction (or inlet) and discharge (or outlet) valve bores. The maximum stress in the fluid end occurs when one plunger (for example, a lateral plunger) is approaching Top Dead Center (TDC), another is approaching Bottom Dead Center (BDC), and a third has just started moving from BDC to TDC.

[0054] It has further been discovered that, to reduce fluid end stress, some or all of the lateral (outside) valve bores 57a, 57c, 59a, 59c at the suction and discharge side may be inwardly offset so that an axis 65 of at least some of the plunger bores (that is, the lateral plunger bore axes 65a, 65c) does not intersect with a common valve bore axis 63, such that at least one of the lateral valve bore axis 63a or 63c is inwardly offset from its respective lateral plunger bore axes 65a or 65c. This inward lateral offset has been observed to noticeably reduce the stress in the fluid end 15 that arises as a result of fluid flowing therein, especially at the high pressures that can be employed in oilfield operations (for example, with oil well fracking fluid).

[0055] In the three cylinder triplex pump embodiment of Figures 2 and 3 the lateral (or outside) suction and discharge valve bores 59a, 57a and 59c, 57c are each shown as being inwardly offset and to the same extent from the associated lateral (or outside) plunger bores 61a and 61c. The central suction and discharge valve bores 59b, 57b are not offset from their respective plunger bores 61b. Thus, the terminology "offset inwardly and to the same extent" can be considered as meaning offset inwardly in relation, or with reference, to the central plunger bore 61b and central valve bores 57b,

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59b. In addition, it will be seen that the common axis 63a of the valve bores 59a, 57a is offset inwardly from the axis 65a of plunger bore 61a. Further, it will be seen that the common axis 63c of the valve bores 59c, 57c is offset inwardly and to the same extent from the axis 65c of the plunger bore 61c.

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[0056] Furthermore, whilst in this embodiment the amount of inward offset from both the lateral plunger bores and axes toward the central plunger bore and axis is the same, the amount of offset can be different. For example, the suction and discharge valve bores on one side can be more or less laterally offset to that of the suction and discharge valve bores on the other side of the fluid end. Additionally, either or both of the suction and discharge valve bores on one side may be laterally offset by different extents, or one may not be offset at all, and this offset may be different to each of the suction and discharge valve bores on the other side of the fluid end, which also may be offset differently to each other.

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[0057] In any case, the inward offsetting of both the lateral suction and discharge valve bores 59a, 57a and 59c, 57c, by the same amount and to the same extent, has been surprisingly observed to maximize stress reduction within the fluid end at the high fluid operating pressures, as explained in Example 1.

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[0058] As indicated above, in the three cylinder triplex pump embodiment of Figures 2 and 3, the common axis 63b of the central suction and discharge valve bores 59b, 57b intersects with axis 65b of the central plunger bore 61b. It has been observed that in a fluid end having three or more cylinders, there is less stress concentration at the intersection of the central plunger bore 61b with the central valve bores 57b, 59b as compared to the stress at the intersections of the lateral bores and their respective plungers, and hence offsetting the central valve bores 57b, 59b may not be required. However, the embodiments of Figures 5 and 6 provide that the central valve bores 59b, 57b and axes can also be offset (for example, maybe to a lesser degree than the lateral bores) to reduce stress concentration thereat.

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[0059] In the embodiment of Figures 2 and 3, each common axis 63 of the valve bores 57 and 59 extends perpendicularly to the plunger bore axis 65, although the lateral axes 63a and 63c do not intersect.

5 [0060] The amount of inward offset of the valve bores 59, 57 and the plunger bores 61 can be significant. For example, for 4.5 inch diameter bores, the valve bore 59, 57, may be inwardly offset 2 inches from a respective plunger bore 61. The amount of inward offset may be measured from axis to axis. For example, the distance can be set by referring to the distance that the common axis 63a or 63c of the valve bores 57a or 57c
10 and 59a or 59c is offset either from its respective plunger bore axis 65a or 65c, or from the central plunger bore axis 65b (or where the central valve bore is not offset, as offset from the central common axis 63b of the valve bores 57b and 59b).

[0061] In any case, the amount of the offset can be about 40% of the diameter of the
15 plunger bore, though it can, for example, range from about 10% to about 60%. Where the inward offset of each of the lateral valve bores 59a, 59c and 57a, 57c is 2 inches, the distance from axis 63a of valve bores 59a, 57c to axis 63c of valve bores 59c, 57c thus becomes 4 inches closer than in known fluid ends of similar dimensions.

20 [0062] In other embodiments, the inward offset of each lateral valve bore can range from about 0.25 inch to about 2.5 inch; from about 0.5 inch to about 2.0 inch; from about 0.75 inch to about 2.0 inch; from about 1 inch to about 2 inch; from about 0.25 inch to about 1.25 inch; from about 1.5 inch to about 2.5 inch; from about 1.5 inch to about 2.0 inch; or from about 1.5 inch to about 1.75 inch.

25 [0063] This moving of the lateral valve bores inwardly can represent a significant reduction in the overall dimension and weight of the fluid end. However, one limit to the amount of inward offset of the lateral (or outside) valve bores toward the central valve bore can be the amount of supporting metal between the valve bores.

30 [0064] When the lateral (or outside) suction valve bores 59 are inwardly offset as described with reference to Figure 2, modification of the suction manifold 19 (Figures

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1A and 1B) can allow for its easy connection to the new fluid end 15. Similar modifications can be employed for the discharge manifold.

[0065] A conventional suction manifold corresponds to conventional bolt patterns that would be located at a greater distance than that occurring between the valve bores 59a, 57a, to valve bores 59c, 57c depicted in Figure 2. The new bolt pattern 71 is illustrated in Figure 3, which schematically depicts an underside of the fluid end 15. In this regard, the distance 74 of the axis 63a of the valve bore 59a to the axis 63c of the valve bore 59c is shorter than the distance 72 between the axis 65a of the plunger bore 61a to the axis 65c of the plunger bore 61c, the latter of which corresponds to the conventional bolt pattern. It is feasible to modify and utilize a manifold with the new bolt pattern.

[0066] Referring now to Figure 4, a similar view of the triplex to Figure 2 is provided, and like reference numerals are used to denote like parts. However, in this embodiment of the triplex, only one of the lateral (or outside) valve bores is offset inwardly from its respective plunger bore, with the other not being offset.

[0067] In Figure 4 the lateral valve bores 57a and 59a are shown as being inwardly offset from their respective plunger bore 61a, 65a (that is, offset towards the central plunger bore axis 65b). In Figure 4 the opposite lateral valve bores 57c and 59c are not offset from their respective plunger bore 61c.

[0068] In another embodiment shown in Figures 5 and 6, the suction valve bores 59b, 59c and the discharge valve bores 57b, 57c corresponding to the plunger bores 61b, 61c are offset to the left and to the same extent. The suction and discharge valve bores 59a and 57a corresponding to the plunger bore 65a are not offset.

[0069] Alternatively, the suction valve bores 59a, 59b and the discharge valve bores 57a, 57b corresponding to the plunger bores 61a, 61b may be offset to the right and to the same extent (not shown). In this alternative, the suction and discharge valve bores 59c, 57c that correspond to the plunger bore 61a would not be offset.

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[0070] In the embodiment of Figures 5 and 6, an axis 63b, 63c of each of the valve bores 59b, 59c and 57b, 57c is offset to the left of an axis 65b, 65c of the respective plunger bores 61b, 61c. Due to the uniform offset of the valve bores 59b, 59c, 57b, 57c associated with each of the plunger bores 61b, 61c, an existing part of the manifold bolt pattern can be employed. However, for the non-offset valve bores 59a, 57a, in effect, a new (shifted) bolt pattern is required.

[0071] In another embodiment shown in Figure 7, the lateral discharge valve bores 57a and 57c are shown being inwardly offset and to the same extent, while the central discharge valve bore 57b and the suction valve bores 59a, 59b, 59c all remain aligned with their respective plunger bores 61a, 61b and 61c. Thus, an axis 63a' and 63c' of each of the two lateral discharge valve bores 57a and 57c is offset from its respective plunger bore axis 65a and 65c, whereas the common axis 63b and the axes 63a'' and 63c'' of the lateral suction valve bores 59a and 59c intersect with their respective axes 65a-c of the plunger bores 61a-c. In this embodiment, the offset of the discharge valve bores 57a and 57c again provides a reduction in stress within the fluid end at these cross bore intersections.

[0072] Due to the non-uniform offset of the discharge valve bores, a conventional discharge manifold is not employed and instead a modified discharge manifold is bolted onto the discharge fluid end 15 of this embodiment. However, a conventional suction manifold may be employed.

[0073] In another embodiment shown in Figure 8, the suction valve bores 59a and 59c are shown being inwardly offset and to the same extent, while the central suction valve bore 59b and the discharge valve bores 57a, 57b, 57c all remain aligned with their respective plunger bores 61a, 61b and 61c. Thus, an axis 63a'' and 63c'' of each of the two lateral suction valve bores 59a and 59c is offset from its respective plunger bore axis 65a and 65c, whereas the common axis 63b and the axes 63a' and 63c' of the lateral discharge valve bores 57a, 57c intersect with their respective axes 65a-c of the plunger bores 61a-c. In this embodiment, the offset of the suction valve bores 59a and

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59c again provides a reduction in stress within the fluid end at these cross bore intersections.

5 [0074] Due to the non-uniform offset of the suction valve bores a conventional suction manifold is not employed and instead a modified suction manifold is bolted onto the suction fluid end 15 of this embodiment. However, a conventional discharge manifold may be employed.

10 [0075] It should be noted that the offsetting of just the lateral suction valve bores, or the offsetting of just the lateral discharge valve bores, can also be employed in a quint fluid end set-up, although this is not illustrated to avoid repetition.

15 [0076] Referring now to Figures 9 and 10, a first embodiment of a quint fluid end (that is, a quintuplex fluid end having five plungers, five suction valves and five discharge valve bores) is shown. Figure 9 is a partial section of Figure 1A taken on the line 2-2 (noting that Figure 1A can also relate to a quint). Figure 10 is an underside schematic view of the section of Figure 9 to show a bolt pattern on a fluid end of a cylinder. For a symmetrical quint fluid end, a central bore of the five plunger bores lies on a central axis of the fluid end, with two plunger bores arranged evenly on either side of the central plunger bore. Again, inward offset may be with respect to a central axis of the fluid end.

25 [0077] In the embodiment of Figures 9 and 10 each of the five plunger bores 17 is indicated schematically with the reference numeral 91 (that is, 91a, 91b, 91c, 91d and 91e); each of the three suction valve bores is indicated schematically with the reference numeral 89 (that is, 89a, 89b, 89c, 89d and 89e); and each of the three discharge valve bores is indicated schematically with the reference numeral 87 (that is, 87a, 87b, 87c, 87d and 87e). Similarly, the axis of each plunger bore 91 is indicated schematically with the reference numeral 95 (that is, 95a, 95b, 95c, 95d and 95e). Also, the common axis of each of the valve bores 89, 87 is indicated schematically with the reference numeral 93 (that is, 93a, 93b, 93c, 93d and 93e). This nomenclature will also be used hereafter with reference to the different quint fluid end embodiments described herein.

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[0078] In the quint fluid end embodiment of Figures 9 and 10 the two lateral valve bores 89a and 87a; 89b and 87b; 89d and 87d; 89e and 87e on each side of the central valve bores 89c and 87c are shown as being inwardly offset from their respective
5 plunger bores 91a, 91b, 91d and 91e.

[0079] In the embodiment of Figures 9 and 10, each of the two lateral valve bores on either side of the central valve bores is inwardly offset by the same amount and to the same extent. However, with a quint fluid end, many more variations and offset
10 combinations are possible than with a triplex fluid end. For example, just two of the lateral suction valve bores 89a and 89b (and not their respective discharge valve bores 87a and 87b) may be inwardly offset, and these two suction valve bores 89a and 89b may each be offset by the same or different amounts. This inward offset may, or may not, be employed for the opposite two lateral suction valve bores 89d and 89e. The
15 inward offset may be employed for the opposite two lateral discharge valve bores 87a and 87b, which latter two might also each be offset by the same or by different amounts, and so on.

[0080] Referring to the new bolt pattern of Figure 10, modification of the suction
20 manifold can allow for its easy connection to the new quint fluid end. As mentioned above, a conventional suction manifold corresponds to conventional bolt patterns that are located at a greater distance than that occurring between the valve bores 89a, 87a, to valve bores 89e, 87e depicted in Figure 10. The new bolt pattern 101 is illustrated in Figure 10, which schematically depicts an underside of the fluid end 15. In this regard,
25 the distance 104 of the axis 93a of the valve bore 89a to the axis 93e of the valve bore 89e is shorter than the distance 102 between the axis 95a of the plunger bore 91a to the axis 95e of the plunger bore 91e, the latter of which corresponds to the conventional bolt pattern. Again, it is feasible to modify and utilize a manifold with the new bolt pattern.

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[0081] Referring now to Figure 11, another embodiment of a quint fluid end is shown. Figure 11 shows a similar view to the quint of Figure 9, but in this embodiment

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illustrates the inward offsetting from their respective plunger bores 91a and 91e of just the outermost lateral valve bores 89a and 87a and 89e and 87e on each side of the central valve bores 89c and 87c. The other lateral valve bores 89c and 87c and 89d and 87d are not offset.

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[0082] Referring now to Figure 12, yet another embodiment of a quint fluid end is shown. Figure 12 shows a similar view to the quint of Figure 11, but in this embodiment illustrates the inward offsetting from its respective plunger bore 91a of just one of the outermost lateral valve bores 89a and 87a. The other lateral valve bores 89b and 87b, 89d and 87d, and 89e and 87e are not offset.

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[0083] Referring now to Figure 13, yet a further embodiment of a quint fluid end is shown. Figure 13 shows a similar view to the quint of Figure 9, but in this embodiment illustrates the inward offsetting from their respective plunger bores 91a and 91e of just the innermost lateral valve bores 89b and 87b, and 89d and 87d, on each side of the central valve bores 89c and 87c. The outermost lateral valve bores 89a and 87a, and 89e and 87e are not offset.

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[0084] Referring now to Figure 14, a yet further embodiment of a quint fluid end is shown. Figure 14 shows a similar view to the quint of Figure 13, but in this embodiment illustrates the inward offsetting from its respective plunger bore 91a of just one of the innermost lateral valve bores 89b and 87b. The other lateral valve bores 89a and 87a, 89d and 87d, and 89e and 87e are not offset.

20

25 **Example**

[0085] A non-limiting example will now be provided to illustrate how the inward offsetting of a lateral valve bore was predicted by finite element analysis (FEA) to reduce the overall amount of stress in a fluid end in operation. In the following example, the FEA tests were conducted for a triplex fluid end, although it was noted that the findings also applied to a quintuplex fluid end.

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[0086] The FEA experiments were conducted to compare the stresses induced in a number of new fluid end configurations having three cylinders against a known (existing and unmodified) three cylinder fluid end configuration. In the known fluid end configuration the axis of each plunger bore intersected perpendicularly with a common
5 axis of the suction and discharge valve bores.

[0087] In these FEA stress tests, each fluid end was subjected to a working fluid pressure of 15,000psi, commensurate with that experienced in usual applications. The pressure of fluid in the lateral discharge bore was observed by FEA to be 16,800psi.

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[0088] Figures 15 and 16 show two of the schematics of a triplex fluid end that were generated by FEA at these model fluid pressures. The view in Figure 15 is from one side of the fluid end and shows no offset of the discharge and suction valve bores 59 and 57. The head of the lower arrow illustrates where maximum stress occurred at the
15 intersection of the plunger bore 61 with the suction valve bore 57 (that is, where the suction valve bore 57 intersects with the extension of the plunger bore 61 which terminates at the suction cover plate 22).

[0089] The view in Figure 16 is from an opposite side of the fluid end and shows a 2
20 inch inward offset of the discharge and suction valve bores 59 and 57. The head of the arrow A illustrates where maximum stress occurred at the intersection of the plunger bore 61 with the suction valve bore 57 (that is, where the plunger bore 61 first intersects with the suction valve bore 57). This indicates that, in operation, stress in the fluid end may be reduced, for example, by the inward offsetting just one of the suction valve
25 bores 59. However, greater stress reduction may also be achieved by the inward offsetting of the opposing lateral suction and discharge valve bores 59 and 57.

[0090] Example 1

In the FEA stress tests, a single (or mono) block fluid end and a triplex fluid end were
30 each modeled. The triplex fluid end configurations modeled included one lateral suction valve bore 59 and one discharge valve bore 57 each being inwardly offset by 1.5 inches and by 2 inches as indicated in Figure 17. Each stress result predicted by FEA was

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correlated to the Von Mises yield criterion (in psi) and the results were plotted for each of zero offset (that is, an existing fluid end), and 1.5 inch and 2 inch offset (that is, a new fluid end). With the single block fluid end, the suction and discharge valve bores were offset from the plunger bore.

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[0091] The stress result predicted by FEA was correlated to the Von Mises yield criterion (in psi) and the results were plotted for each of 0 inch offset (that is, an existing fluid end), and 1.5 inch and 2 inch offset (that is, new fluid end). The results are shown in the graphs of Figure 17 (which shows data point results for both 1.5 inch and 2 inch offset) and Figure 18 (which represents the results for 1.5 inch and 2 inch inward offset in a bar chart).

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[0092] As can be seen, FEA predicted that the greatest amount of stress reduction occurred with the 2 inch inward offset configuration of the valve bores in a triplex. For a single block fluid end the modeling of offset did not produce much of reduction in stress.

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[0093] The overall stress reduction in the triplex fluid end for a 2 inch inward offset was noted to be approximately 30% (that is, from ~ 97,000 psi to less than 69,000 psi as shown in Figures 17 and 18). It was noted that such a stress reduction would be likely to significantly extend the useful operating life of the fluid end.

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[0094] In the foregoing description of certain embodiments, specific terminology has been resorted to for the sake of clarity. However, the disclosure is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes other technical equivalents which operate in a similar manner to accomplish a similar technical purpose. Terms such as “left” and “right”, “front” and “rear”, “above” and “below”, “top” and “bottom” and the like are used as words of convenience to provide reference points and are not to be construed as limiting terms.

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[0095] In this specification, the word “comprising” is to be understood in its “open” sense, that is, in the sense of “including”, and thus not limited to its “closed” sense, that

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is the sense of “consisting only of”. A corresponding meaning is to be attributed to the corresponding words “comprise”, “comprised” and “comprises” where they appear.

[0096] In addition, the foregoing describes only some embodiments of the fluid end and reciprocating pump, and alterations, modifications, additions and/or changes can be made thereto without departing from the scope and spirit of the disclosed embodiments, the embodiments being illustrative and not restrictive.

[0097] Furthermore, the fluid end and reciprocating pump have described in connection with what are presently considered to be the most practical and preferred embodiments, it is to be understood that the fluid end and reciprocating pump are not to be limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the disclosure. Also, the various embodiments described above may be implemented in conjunction with other embodiments, for example, aspects of one embodiment may be combined with aspects of another embodiment to realize yet other embodiments. Further, each independent feature or component of any given assembly may constitute an additional embodiment.

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WHAT IS CLAIMED IS:

1. A fluid end for a multiple reciprocating pump assembly, the fluid end comprising:
 - at least three plunger bores each for receiving a reciprocating plunger, each
 - 5 plunger bore having a plunger bore axis, the plunger bores being arranged across the fluid head to define a central plunger bore and lateral plunger bores located on either side of the central plunger bore;
 - at least three respective suction valve bores in fluid communication with the plunger bores, each suction valve bore for receiving a suction valve and having a
 - 10 suction valve bore axis;
 - at least three respective discharge valve bores in fluid communication with the plunger bores, each discharge valve bore for receiving a discharge valve and having a discharge valve bore axis;
 - wherein at least one of the axes of at least one of the suction and discharge valve
 - 15 bores for at least one of the lateral plunger bores is inwardly offset in the fluid end from its respective plunger bore axis.
2. A fluid end according to claim 1 wherein at least one of the axes of at least one of the suction and discharge valve bores for each of the lateral plunger bores is inwardly
- 20 offset.
3. A fluid end according to claim 2 wherein, for the lateral plunger bores, the at least one offset axis is inwardly offset to the same extent as the other at least one offset axis.
- 25 4. A fluid end any one of the preceding claims wherein the axes of both the suction and discharge valve bores are inwardly offset for at least one of the lateral plunger bores.
5. A fluid end according to claim 4 wherein the axes of both the suction and discharge valve bores are inwardly offset to the same extent.
- 30 6. A fluid end according to any one of the preceding claims wherein, for each of the plunger bores, the suction valve bore opposes the discharge valve bore.

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7. A fluid end according to claim 6 wherein, for each of the plunger bores, the axes of the suction and discharge valve bores are aligned.
- 5 8. A fluid end according to any one of the preceding claims wherein, the fluid end comprises three or five plunger bores, and three or five corresponding suction and discharge valve bores.
9. A fluid end according to any one of the preceding claims wherein, for the lateral
10 plunger bores, the at least one axis is inwardly offset in an amount of from about 10% to about 60% of the diameter of the plunger bore.
10. A fluid end according to any one of the preceding claims wherein the at least one axis is offset in an amount ranging from about 20% to about 50% of the diameter of the
15 plunger bore.
11. A fluid end according to any one of the preceding claims wherein the at least one axis is offset in an amount ranging from about 30% to about 40% of the diameter of the
20 plunger bore.
12. A fluid end according to any one of claims 1 to 8 wherein the at least one axis is offset in an amount ranging from about 0.5 to about 2.5 inches.
13. A fluid end according to any one of claims 1 to 8 wherein the at least one axis is
25 offset in an amount ranging from about 1.5 to about 2.5 inches.
14. A reciprocating pump assembly comprising a fluid end according to any one of the preceding claims.
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