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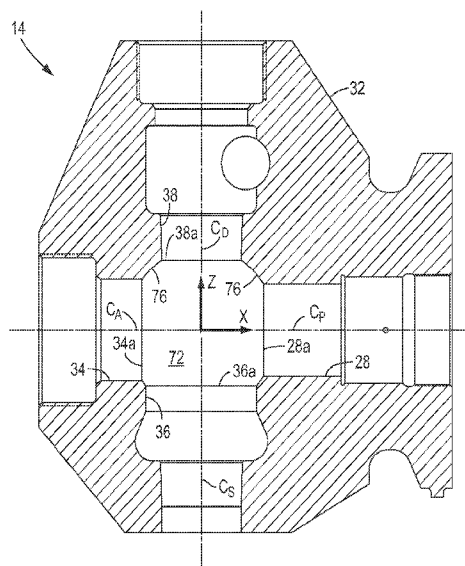


FIG. 6

(57) Abstract: A reciprocating pump comprising a fluid end housing having a number of plunger sections, each of which includes a plunger bore within which a plunger is slidably received, a suction bore within which a suction valve is positioned, a discharge bore within which a discharge valve is positioned, and a cross bore chamber which is located between said bores and is configured as a surface of revolution. Each of the bores intersects the cross-bore chamber to thereby define a respective cross curve which is spatially separated from each adjacent cross curve. In this manner, the cross-bore chamber defines a single, contiguous surface which extends around and between all of said cross curves.

RECIPROCATING PUMP WITH IMPROVED FLUID CYLINDER
CROSS-BORE GEOMETRY

BACKGROUND OF THE INVENTION

5 The present invention is related to reciprocating plunger and piston-type pumps which are used, for example, in oil well service operations. In particular, the invention is related to an improved cross-bore geometry for the fluid end of such pumps.

10 Plunger pumps for the oilfield industry typically include a power end and a fluid end. The fluid end generally includes a plunger which is positioned in a plunger bore and is reciprocated by the power end, an access bore which is located opposite the plunger bore, a suction valve which is positioned in a suction bore and a discharge valve which is positioned in a discharge bore. In operation, the plunger is reciprocated in the plunger bore to alternately draw fluid into the pump through the suction valve and then force the fluid out of the pump through
15 the discharge valve.

During operation of the pump, the fluid end is subject to very high frequency and large magnitude pressure pulsations. These pressure pulsations generate large stress concentrations at the intersections of the bores. In cross-bore geometries in which the bore intersections form relatively sharp edges,
20 these stress concentrations may cause fatigue cracks to form in the fluid end proximate the intersections. In some prior art pumps, the intersecting edges of the bores are machined to have quasi radii and chamfered features in an attempt to smooth the bore intersections. Although smoothing the bore intersections in this manner may reduce the stress concentrations to a certain extent, the cross-bore geometries of extreme service pumps remain susceptible to developing
25 excessive stress concentrations due to the limitations imposed by the current configurations of the bore intersections.

SUMMARY OF THE INVENTION

30 In accordance with the present invention, these and other limitations in the prior art are overcome by providing a reciprocating pump comprising a fluid end housing having a number of plunger sections, each plunger section including a plunger bore within which a plunger is slidably received, a suction bore within which a suction valve is positioned, a discharge bore within which a discharge valve is positioned, and a cross bore chamber which is located between said

bores and is configured as a surface of revolution. Each of said bores intersects the cross-bore chamber to thereby define a respective cross curve which is spatially separated from each adjacent cross curve. In this manner, the cross-bore chamber defines a single, contiguous surface which extends around and
5 between all of said cross curves.

In accordance with one embodiment of the invention, the cross-bore chamber is configured as an ellipsoid. In this embodiment, the ellipsoid may comprise a first axis which is coaxial with a centerline of the plunger bore and a second axis which is coaxial with at least one of a centerline of the suction bore
10 and a centerline of the discharge bore. Alternatively, the ellipsoid may comprise a first axis which is coaxial with a centerline of the plunger bore and a second axis which is parallel to but offset from at least one of a centerline of the suction bore and a centerline of the discharge bore. Alternatively, the ellipsoid may comprise a first axis which is parallel to but offset from a centerline of the plunger
15 bore and a second axis which is coaxial with at least one of a centerline of the suction bore and a centerline of the discharge bore. Alternatively, the ellipsoid may comprise a first axis which is parallel to but offset from a centerline of the plunger bore and a second axis which is parallel to but offset from at least one of a centerline of the suction bore and a centerline of the discharge bore.

In accordance with another embodiment of the invention, each plunger section further comprises an access bore which intersects the cross-bore chamber to thereby define a corresponding cross curve that is spatially separated from each adjacent cross curve. In this manner, the cross-bore chamber defines a single, contiguous surface which extends around and between all of said cross
20 curves. In this embodiment, the cross-bore chamber may be configured as an ellipsoid. In addition, the access bore may be generally aligned with the plunger bore and the suction bore may be generally aligned with the discharge bore, and the access and plunger bores may be oriented at an angle of generally ninety degrees relative to the suction and discharge bores. Also, the ellipsoid may
25 comprise a first axis which is coaxial with a centerline of the plunger bore and a second axis which is coaxial with at least one of a centerline of the suction bore and a centerline of the discharge bore. Alternatively, the ellipsoid may comprise a first axis which is coaxial with a centerline of the plunger bore and a second axis which is parallel to but offset from at least one of a centerline of the suction
30

bore and a centerline of the discharge bore. Alternatively, the ellipsoid may comprise a first axis which is parallel to but offset from a centerline of the plunger bore and a second axis which is coaxial with at least one of a centerline of the suction bore and a centerline of the discharge bore. Alternatively, the ellipsoid
5 may comprise a first axis which is parallel to but offset from a centerline of the plunger bore and a second axis which is parallel to but offset from at least one of a centerline of the suction bore and a centerline of the discharge bore.

In accordance with a further embodiment of the invention, the plunger bore, the suction bore and the discharge bore are oriented at an angle of
10 approximately 120 degrees relative to each other. In this embodiment, the ellipsoid may comprise a first axis which is coaxial with a centerline of the plunger bore and a center point which is located at an intersection of the plunger bore, the suction bore and the discharge bore. Alternatively, the ellipsoid may comprise a first axis which is coaxial with a centerline of the plunger bore and a
15 center point which is offset from an intersection of the plunger bore, the suction bore and the discharge bore. Alternatively, the ellipsoid may comprise a first axis which is parallel to but offset from a centerline of the plunger bore and a center which is located at an intersection of the plunger bore, the suction bore and the discharge bore. Alternatively, the ellipsoid may comprise a first axis which is
20 parallel to but offset from a centerline of the plunger bore and a center which is offset from an intersection of the plunger bore, the suction bore and the discharge bore.

The present invention is also directed to a method of reducing stress concentrations in a fluid end housing of a reciprocating pump, the fluid end
25 housing having a number of plunger sections, each plunger section including a plunger bore within which a plunger is slidably received, a suction bore within which a suction valve is positioned and a discharge bore within which a discharge valve is positioned. The method comprises forming a cross-bore chamber between said bores, said cross-bore chamber being configured as a surface of
30 revolution, wherein each of said bores intersects the cross-bore chamber to thereby define a respective cross curve which is spatially separated from each adjacent cross curve. In this manner, the cross-bore chamber defines a single, contiguous surface which extends around and between all of said cross curves.

In accordance with one aspect of this embodiment, the cross-bore chamber may be configured as a spheroid.

Thus, in accordance with the present invention an improved cross-bore geometry is obtained by creating a cross-bore chamber at the intersection of the plunger bore, the suction bore, the discharge bore and, if present, the access bore. The cross-bore chamber is configured as a surface of revolution which is created by rotating a two-dimensional curve around a reference axis. For example, the cross-bore chamber may be configured as an ellipsoid, a particular case of which is a sphere. By configuring the cross-bore chamber as a surface of revolution such as an ellipsoid, the cross-bore chamber provides a single, smooth contiguous connecting surface between the bores. As a result, the stress concentrations in the cross-bore geometry are significantly reduced, and the fluid end is therefore less susceptible to failure.

These and other objects and advantages of the present invention will be made apparent from the following detailed description, with reference to the accompanying drawings. In the drawings, the same reference numbers are used to denote similar components in the various embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective, partial cut-away view of a prior art plunger pump in which the cross-bore geometry of the present invention may be incorporated;

Figure 2 is a cross sectional view of the fluid end of the plunger pump shown in Figure 1;

Figure 3 is a cross sectional view similar to Figure 2 but with the internal components of the fluid end removed for clarity;

Figure 4 is a schematic representation of the cross bore geometry in accordance with one embodiment of the present invention;

Figure 5 is a perspective, cut-away view of an embodiment of a fluid end of the present invention having an illustrative cross bore geometry;

Figure 6 is a cross sectional view of the fluid end shown in Figure 5;

Figures 7-9 are cross sectional views of additional embodiments of fluid ends having differing illustrative cross-bore geometries; and

Figure 10 is a cross sectional view of another embodiment of a fluid end in which the cross-bore geometry of the present invention may be incorporated.

DETAILED DESCRIPTION OF THE INVENTION

An example of a prior art plunger pump in which the cross-bore geometry of the present invention may be incorporated is shown in Figure 1. As described more fully in U.S. Patent No. 7,610,847, which is hereby incorporated herein by reference, the plunger pump 10 comprises a power end 12 and a fluid end 14.

5 The power end 12 includes a gear reducer assembly 16 which is driven by a suitable motor (not shown). The gear reducer assembly 16 drives a crankshaft 18. The crankshaft 18 is rotatably connected to one end of a connecting rod 20, the opposite end of which is pivotally connected to a crosshead 22 that is supported for linear movement in a corresponding guide bore 24. The fluid end
10 14 includes a number of plungers 26 (only one of which is shown in Figure 1), each of which is slidably mounted in a respective plunger bore 28 and is connected to a respective crosshead 22 by a plunger rod 30. In operation, rotary motion of the crankshaft 18 is converted by the connecting rod 20 into linear reciprocating motion of the crosshead 22, which in turn reciprocates the plunger
15 26 in the plunger bore 28.

The fluid end 14 comprises a laterally extending housing 32 having a number of plunger sections (in this case five) which are each aligned with a corresponding plunger 26. The middle plunger section is shown in greater detail in Figures 2 and 3. With the exception noted below, the middle plunger section is
20 similar to the remaining plunger sections. As described more fully in U.S. Patent No. 7,681,589, which is hereby incorporated herein by reference, the middle plunger section includes a cross bore arrangement comprising the plunger bore 28, an access bore 34 which is generally aligned with the plunger bore, a suction bore 36 which is generally perpendicular to the plunger bore, and a discharge
25 bore 38 which is generally aligned with the suction bore.

The plunger 26 is positioned in the plunger bore 28 and is sealed thereto by, e.g., an annular packing 40, which in the embodiment shown in Figure 2 is mounted in a stuffing box 42 that is secured to the housing 32 by a number of cap screws 44. The access bore 34 is sealed by a plug 46 which is secured to
30 the housing 32 by a first retainer nut 48. A suction valve 50 is positioned in the suction bore 36 between the plunger bore 28 and an inlet port 52. A discharge valve 54 is positioned in the discharge bore 38 between the plunger bore 28 and a pressure tap fitting 56 which is secured in the discharge bore by a second retainer nut 58. The discharge bores 38 of the remaining bore sets are sealed by

plugs 60 (Fig. 1) similar to the plug 48 (Fig. 2), and all of the discharge bores are fluidly connected via a lateral bore 62 to an outlet coupling 63 (Fig. 1). In this manner, all the fluid pumped through the several plunger sections will be directed through the lateral bore 62 and exit the pumping unit 10 through the outlet

5 coupling 63.

As shown in Figure 1, the inlet ports 52 of the several plunger sections are connected to an inlet manifold 64 having a pump inlet 66 which is connectable to, e.g., a source of well service fluid (not shown). In operation of the plunger pump 10, the plungers 26 are reciprocated by the power end 12 in the manner

10 described above. During the suction stroke of each plunger 26, the suction valve 50 is forced open and fluid is drawn through the suction bore 36 and into the plunger bore 28. During the discharge stroke of each plunger 26, the suction valve 50 is forced closed and the fluid in the plunger bore 28 is forced through the discharge valve 54 and the outlet coupling 63. Further details of the operation of
15 the suction valve 50 and the discharge valve can be found in the aforementioned U.S. patent No. 7,681,589.

The cross bore arrangement of each plunger section is shown more clearly in Figure 3, which is similar to Figure 2 but with the internal components of the plunger section removed for clarity. As shown in Figure 3, the plunger bore 28 and the access bore 34 comprise respective centerlines C_P and C_A which are
20 coaxial along an axis X, and the suction bore 36 and the discharge bore 38 comprise respective centerlines C_S and C_D which are coaxial along an axis Z that is perpendicular to the axis X. In this embodiment of the fluid end 14, the suction bore 36 intersects the plunger bore 28 along a first curve 68, and the discharge
25 bore 38 intersects the plunger bore along a second curve 70. As may be seen in Figure 3, the curves 68, 70 define relatively sharp edges between the intersecting bores.

During operation of the pump 10, the fluid end 14 is subject to very high frequency and large magnitude pressure pulsations. These pressure pulsations
30 generate large stress concentrations at the bore intersections. In cross-bore geometries in which the bore intersections form relatively sharp edges, these stress concentrations may cause fatigue cracks to form in the housing proximate the intersections. Traditionally, quasi radii and chamfers have been applied to the bore intersections using hand tools to obtain some semblance of

smoothness. With the advent of robotics and multi-axis machines, these features can be machined programmatically. Although smoothing the bore intersections in this manner may reduce the stress concentrations to a certain extent, the cross-bore geometries of extreme service pumping units remain susceptible to
5 developing excessive stress concentrations due to the limitations imposed by the current configurations of the bore intersections.

According to the present invention, an improved cross-bore geometry has been developed which greatly reduces the stress concentrations that can lead to fatigue cracks in the fluid end originating at and propagating from the bore
10 intersections. The improved cross-bore geometry is obtained by creating a cross-bore chamber at the intersection of the plunger bore, the access bore, the suction bore and the discharge bore. The characteristics of the cross-bore chamber will be described with reference to the schematic representation shown in Figure 4. The cross-bore chamber, generally 72, is configured as a surface of
15 revolution which is created by rotating a two-dimensional curve 74 around one of the X, Y or Z axes. In this regard, the X, Y and Z axes are defined as the reference axes for the surface of revolution. Although in certain embodiments of the invention the X axis may be coaxial with one or both of the plunger bore centerline C_P and the access bore centerline C_A and the Z axis may be coaxial
20 with one or both of the suction bore centerline C_S and the discharge bore centerline C_D , these axes do not necessarily have to be aligned with any of the bore centerlines.

The two-dimensional curve 74 can have any practical configuration, provided that it comprises a diameter which is greater than the diameter of the
25 largest of the plunger bore 28, the access bore 34, the suction bore 36 and the discharge bore 38. In the specific embodiment of the invention illustrated in Figure 4, the curve 74 is an ellipse which is centered at the origin O of the X, Y and Z axes. Thus, the surface of revolution defining the cross-bore chamber 72 has the general shape of an ellipsoid which is centered about the origin O and is
30 created by rotating the ellipse 74 about the X axis. In the context of the present invention, however, the ellipsoid may have any configuration which is defined by the following standard equation:

$$x^2/a^2 + y^2/b^2 + z^2/c^2 = 1,$$

where a , b and c are the respective lengths of the semi-principal axes of the ellipsoid. For example, the cross-bore chamber 72 may be configured as a sphere by making $a = b = c$.

Referring still to Figure 4, the intersection of each of the plunger bore 28, the access bore 34, the suction bore 36 and the discharge bore 38 with the cross-bore chamber 72 defines a respective cross curve 28a, 34a, 36a and 38a. The particular shape of each cross curve will of course depend on the shape of the surface of revolution which defines the cross-bore chamber 72. As may be seen in Figure 4, by configuring the cross-bore chamber 72 as a surface of revolution such as an ellipsoid, the cross-bore chamber provides a single, smooth contiguous connecting surface between each of the cross curves. This single, smooth contiguous connecting surface is created by virtue of the fact that, rather than intersecting each other, the plunger bore 28, the access bore 34, the suction bore 36 and the discharge bore 38 intersect the cross-bore chamber 72. Thus, in the present invention the sharp edge formed by the intersection of, e.g., the discharge bore with the plunger bore, is eliminated. Instead, the smooth contiguous connecting surface formed by the cross-bore chamber 72 extends around and between the cross curves 28a, 34a, 36a and 38a. As a result, the stress concentrations in the cross-bore geometry are significantly reduced, and the fluid end is therefore less susceptible to fatigue crack formation.

Referring to Figures 5 and 6, an embodiment of the invention is shown in which the cross-bore chamber 72 comprises a spherical configuration. In this embodiment, the plunger bore centerline C_P and the access bore centerline C_A are coaxial with the X axis and the suction bore centerline C_S and the discharge bore centerline C_D are coaxial with the Z axis. As may be seen especially in Figure 5, the spherical configuration of the cross-bore chamber 72 forms a single, smooth contiguous connecting surface 76 between and around the cross curves 28a, 34a, 36a and 38a. In this embodiment, the bore with the largest diameter is the suction bore 36, and the sphere defining the cross-bore chamber 72 comprises a diameter which is larger than the diameter of the suction bore. In this as in other embodiments of the invention, the shape and size of the surface of revolution which is used to form the cross-bore chamber 72 may be determined empirically for a particular cross-bore geometry in order to provide desired stress and flow characteristics for the fluid end.

Further illustrative and non-limiting embodiments of the cross bore geometry of the present invention are shown in Figures 7-9. The cross bore geometry shown in Figure 7 is similar to that shown in Figure 6. In the embodiment shown in Figure 7, however, the X axis is offset from the plunger bore centerline C_P and the access bore centerline C_A , which in this case are coaxial. In this example, where the cross-bore chamber 72 is defined by a sphere having a diameter of 8.50", the X axis is offset in the Z direction 0.50" from the plunger bore centerline C_P toward the suction bore 36.

In the embodiment of the cross-bore geometry shown in Figure 8, the X axis is coaxial with the plunger bore centerline C_P and the access bore centerline C_A , but the Z axis is offset from the suction bore centerline C_S and the discharge bore centerline C_D , which in this instance are coaxial. In this example, where the cross-bore chamber 72 is defined by a sphere having a diameter of 8.50", the Z axis is offset in the X direction 0.20" from the discharge bore centerline C_D toward the access bore 34.

In the embodiment of the cross-bore geometry shown in Figure 9, the X axis is offset from the plunger bore centerline C_P and the access bore centerline C_A , which in this instance are coaxial, and the Z axis is offset from the suction bore centerline C_S and the discharge bore centerline C_D , which in this case are also coaxial. In this example, where the cross-bore chamber 72 is defined by a sphere having a diameter of 8.50", the X axis is offset in the Z direction 0.50" from the plunger bore centerline C_P toward the suction bore 36, and the Z axis is offset in the X direction 0.20" from the discharge bore centerline C_D toward the access bore 34.

Another example of a fluid end in which the cross-bore geometry of the present invention may be incorporated is shown in Figure 10. The fluid end of this embodiment, generally 14', is described more fully in U.S. Patent No. 8,147,227, which is hereby incorporated herein by reference. As shown in Figure 10, the fluid end 14' comprises a Y-shaped cross bore arrangement in which the access bore is omitted and the plunger bore 26, the suction bore 36 and the discharge bore 38 are oriented approximately 120° from each other.

In accordance with the present invention, a cross-bore chamber (not shown) may be machined into the fluid end to provide the advantages described above. As in the previous embodiments, the cross-bore chamber may comprise

a surface of revolution, such as an ellipsoid, which is centered at the origin O of the X, Y and Z reference axes. In addition, the X axis may be either aligned with or offset from the plunger bore centerline C_P , and the origin O of the reference axes may be located at or offset from the intersection of the plunger bore
5 centerline C_P , the suction bore centerline C_S and the discharge bore centerline C_D .

It should be recognized that, while the present invention has been described in relation to the preferred embodiments thereof, those skilled in the art may develop a wide variation of structural and operational details without
10 departing from the principles of the invention. Therefore, the appended claims are to be construed to cover all equivalents falling within the true scope and spirit of the invention.

We Claim:

1. In a reciprocating pump comprising a fluid end housing having a number of plunger sections, each plunger section including a plunger bore within which a plunger is slidably received, a suction bore within which a suction valve is positioned and a discharge bore within which a discharge valve is positioned, the improvement comprising a cross bore chamber which is located between said bores and is configured as a surface of revolution, wherein each of said bores intersects the cross-bore chamber to thereby define a respective cross curve which is spatially separated from each adjacent cross curve, whereby the cross-bore chamber defines a single, contiguous surface which extends around and between all of said cross curves.
2. The pump of claim 1, wherein the cross-bore chamber is configured as an ellipsoid.
3. The pump of claim 2, wherein the ellipsoid comprises a first axis which is coaxial with a centerline of the plunger bore and a second axis which is coaxial with at least one of a centerline of the suction bore and a centerline of the discharge bore.
4. The pump of claim 2, wherein the ellipsoid comprises a first axis which is coaxial with a centerline of the plunger bore and a second axis which is parallel to but offset from at least one of a centerline of the suction bore and a centerline of the discharge bore.
5. The pump of claim 2, wherein the ellipsoid comprises a first axis which is parallel to but offset from a centerline of the plunger bore and a second axis which is coaxial with at least one of a centerline of the suction bore and a centerline of the discharge bore.
6. The pump of claim 2, wherein the ellipsoid comprises a first axis which is parallel to but offset from a centerline of the plunger bore and a second axis which is parallel to but offset from at least one of a centerline of the suction bore and a centerline of the discharge bore.
7. The pump of claim 1, wherein each plunger section further comprises an access bore which intersects the cross-bore chamber to thereby define a corresponding cross curve that is spatially separated from each adjacent cross curve, whereby the cross-bore chamber defines a single, contiguous surface which extends around and between all of said cross curves.

8. The pump of claim 7, wherein the cross-bore chamber is configured as an ellipsoid.

9. The pump of claim 8, wherein the access bore is generally aligned with the plunger bore and the suction bore is generally aligned with the discharge bore, and wherein the access and plunger bores are oriented at an angle of generally ninety degrees relative to the suction and discharge bores.

10. The pump of claim 9, wherein the ellipsoid comprises a first axis which is coaxial with a centerline of the plunger bore and a second axis which is coaxial with at least one of a centerline of the suction bore and a centerline of the discharge bore.

11. The pump of claim 9, wherein the ellipsoid comprises a first axis which is coaxial with a centerline of the plunger bore and a second axis which is parallel to but offset from at least one of a centerline of the suction bore and a centerline of the discharge bore.

12. The pump of claim 9, wherein the ellipsoid comprises a first axis which is parallel to but offset from a centerline of the plunger bore and a second axis which is coaxial with at least one of a centerline of the suction bore and a centerline of the discharge bore.

13. The pump of claim 9, wherein the ellipsoid comprises a first axis which is parallel to but offset from a centerline of the plunger bore and a second axis which is parallel to but offset from at least one of a centerline of the suction bore and a centerline of the discharge bore.

14. The pump of claim 2, wherein each of said bores is oriented at an angle of approximately 120 degrees relative to each other bore.

15. The pump of claim 14, wherein the ellipsoid comprises a first axis which is coaxial with a centerline of the plunger bore and a center point which is located at an intersection of the plunger bore, the suction bore and the discharge bore.

16. The pump of claim 14, wherein the ellipsoid comprises a first axis which is coaxial with a centerline of the plunger bore and a center point which is offset from an intersection of the plunger bore, the suction bore and the discharge bore.

17. The pump of claim 14, wherein the ellipsoid comprises a first axis which is parallel to but offset from a centerline of the plunger bore and a center

which is located at an intersection of the plunger bore, the suction bore and the discharge bore.

18. The pump of claim 14, wherein the ellipsoid comprises a first axis which is parallel to but offset from a centerline of the plunger bore and a center
5 which is offset from an intersection of the plunger bore, the suction bore and the discharge bore.

19. A method of reducing stress concentrations in a fluid end housing of a reciprocating pump, the fluid end housing having a number of plunger sections, each plunger section including a plunger bore within which a plunger is slidably
10 received, a suction bore within which a suction valve is positioned and a discharge bore within which a discharge valve is positioned, the method comprising:

forming a cross-bore chamber between said bores, said cross-bore chamber being configured as a surface of revolution;

15 wherein each of said bores intersects the cross-bore chamber to thereby define a respective cross curve which is spatially separated from each adjacent cross curve;

whereby the cross-bore chamber defines a single, contiguous surface which extends around and between all of said cross curves.

20 20. The method of claim 19, wherein said cross-bore chamber is configured as a spheroid.

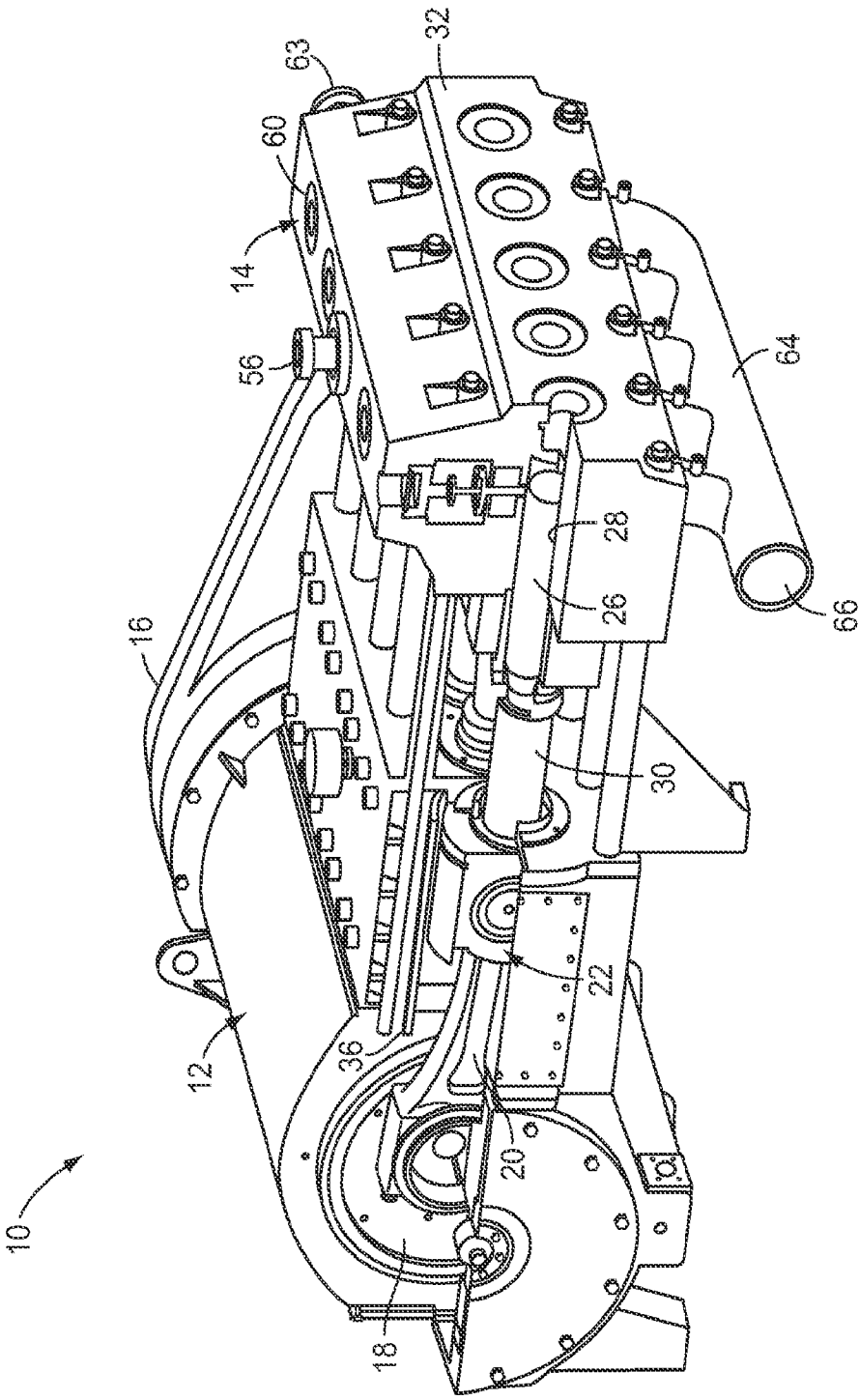


FIG. 1

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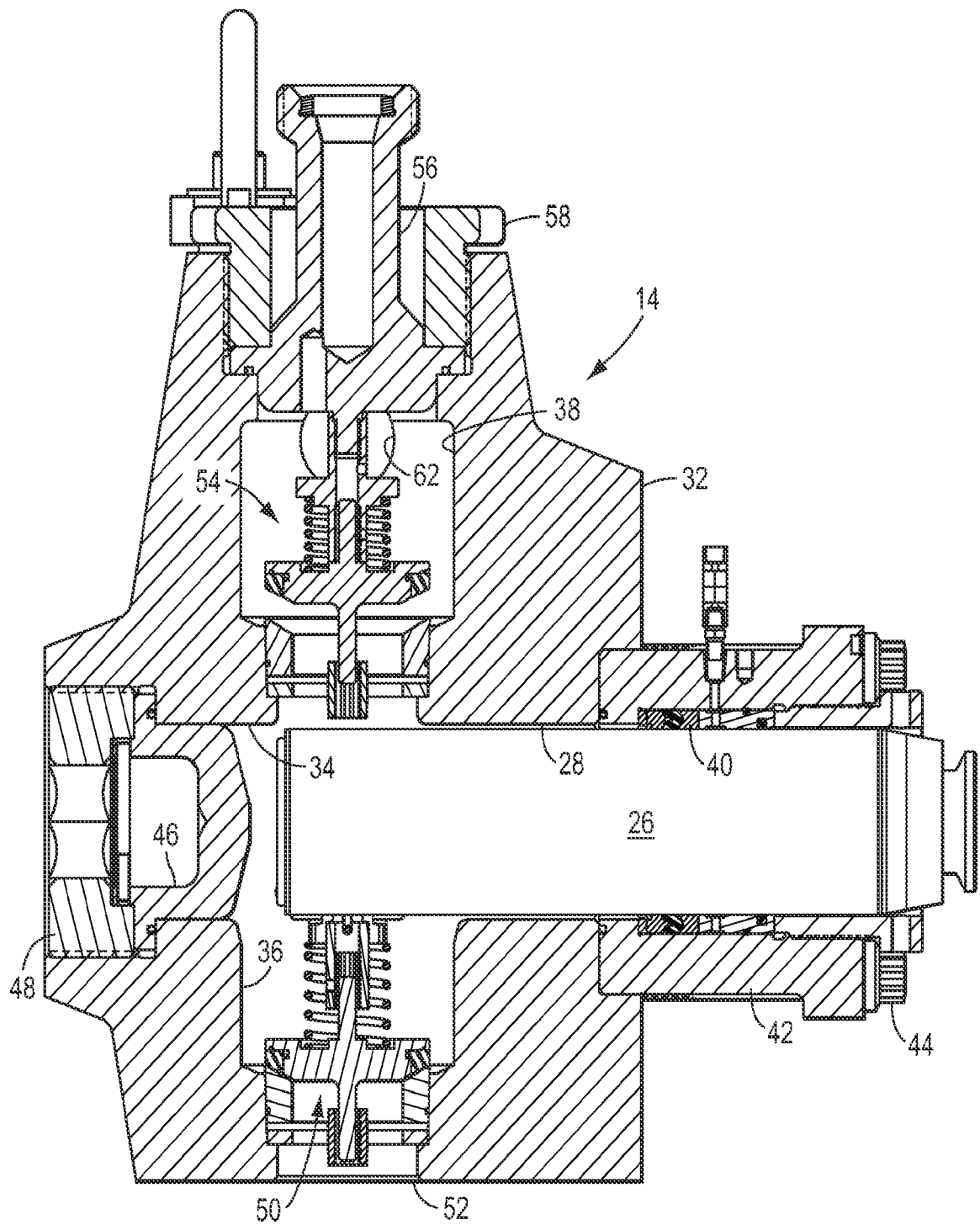


FIG. 2

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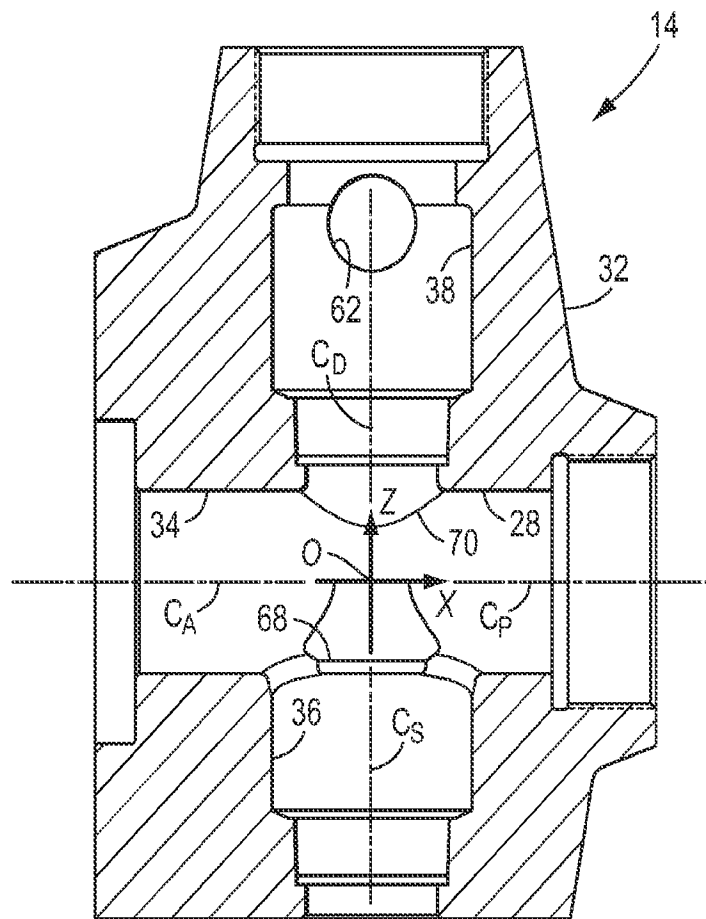


FIG. 3

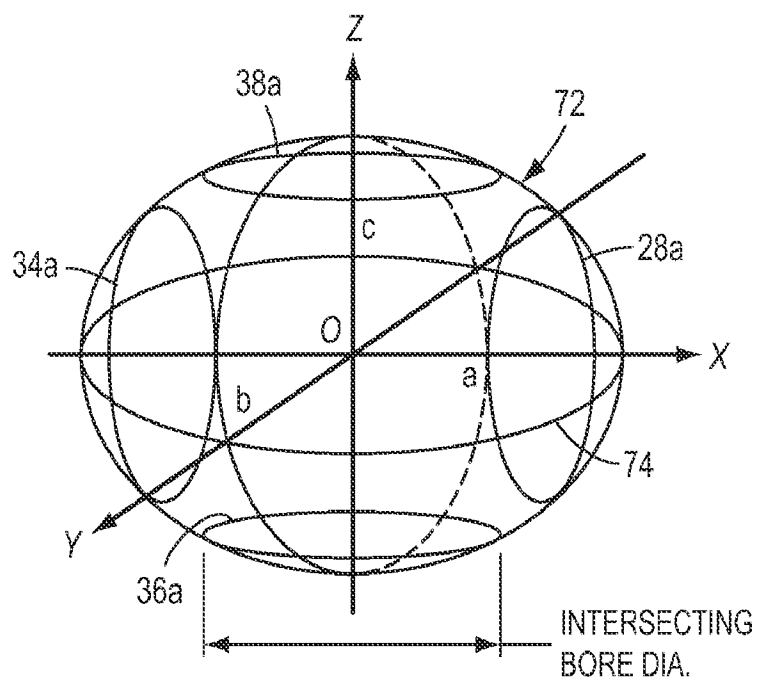


FIG. 4

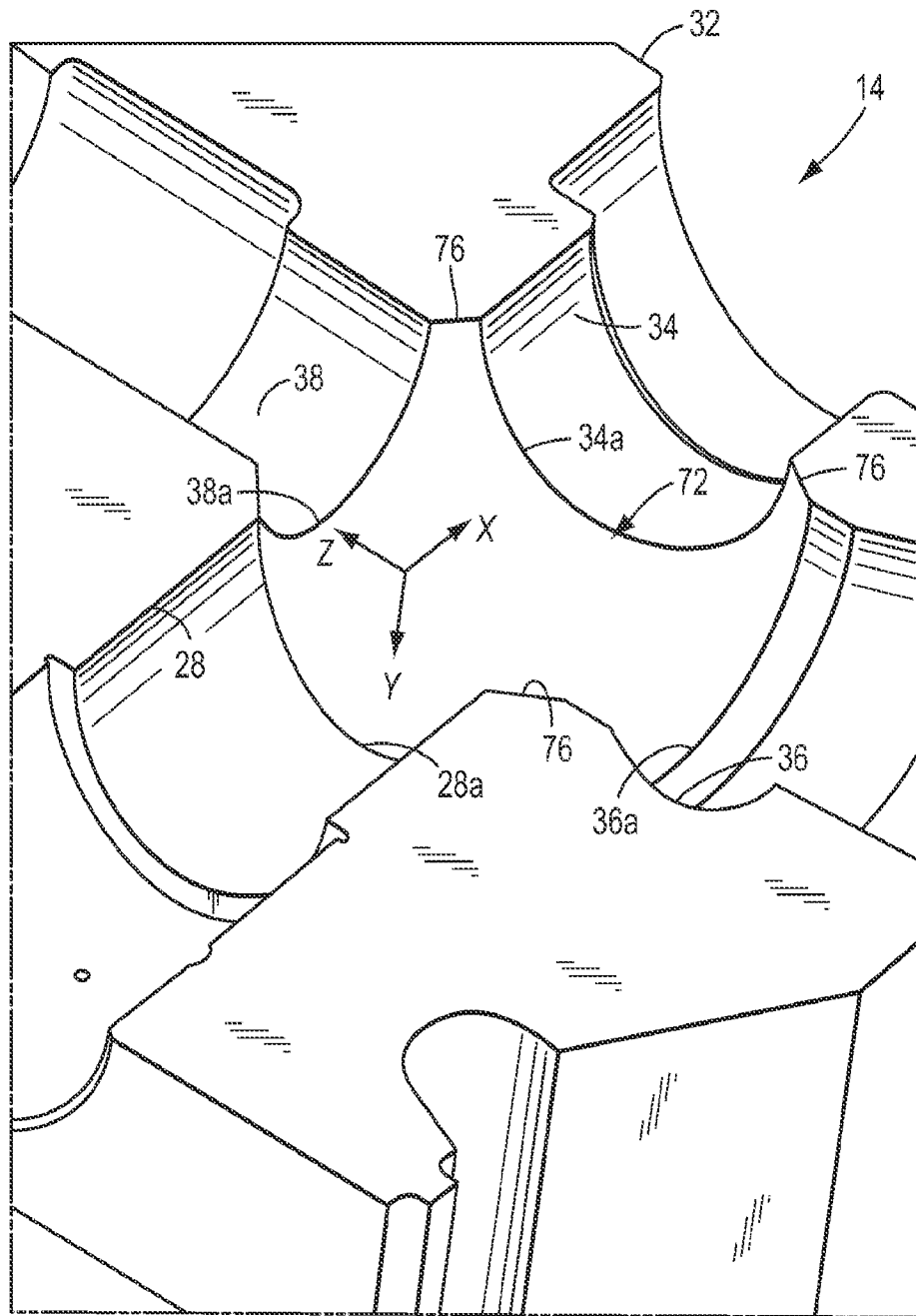


FIG. 5

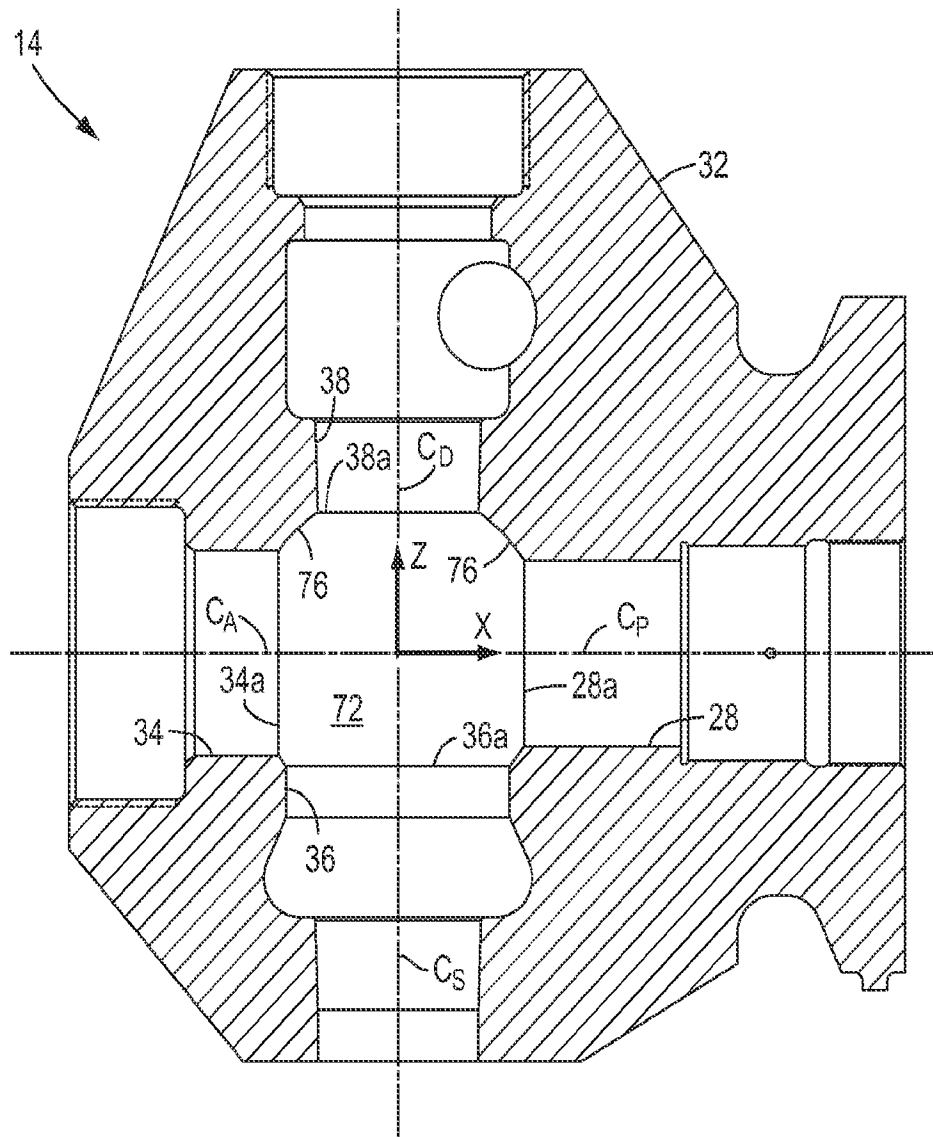


FIG. 6

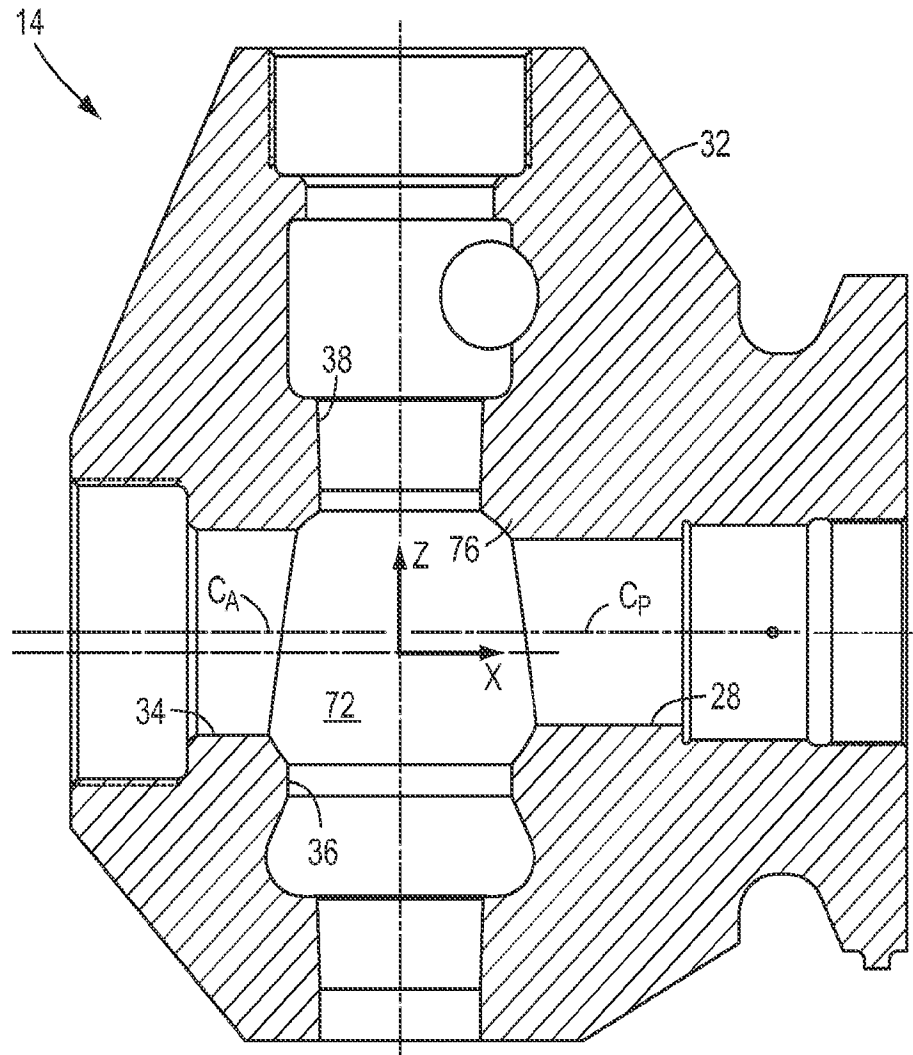


FIG. 7

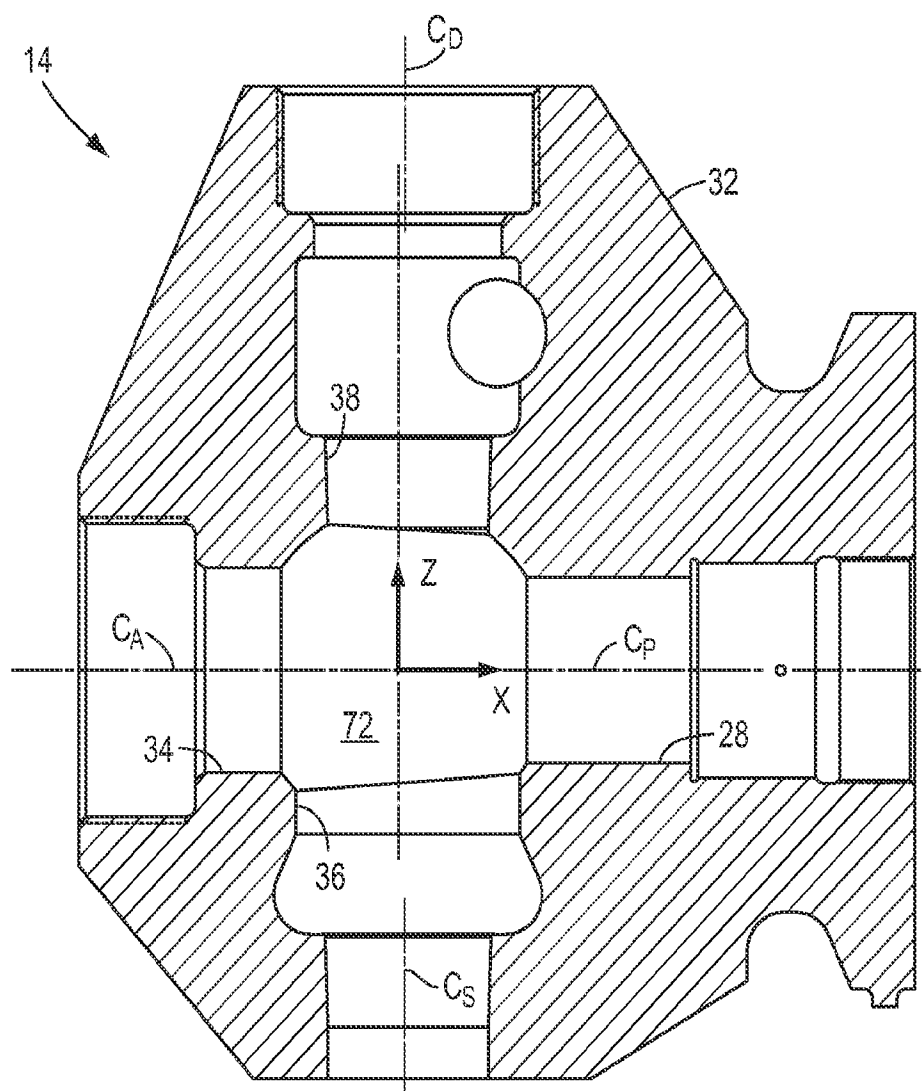


FIG. 8

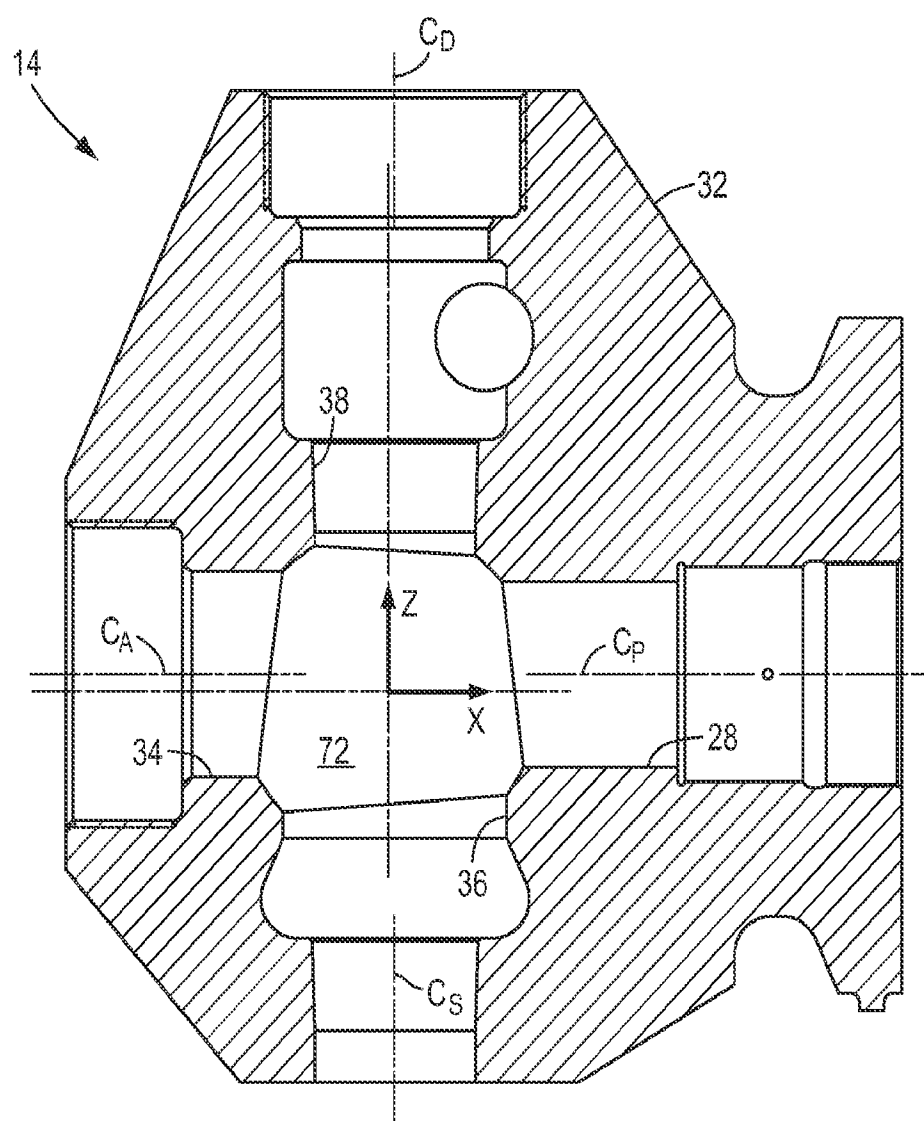


FIG. 9

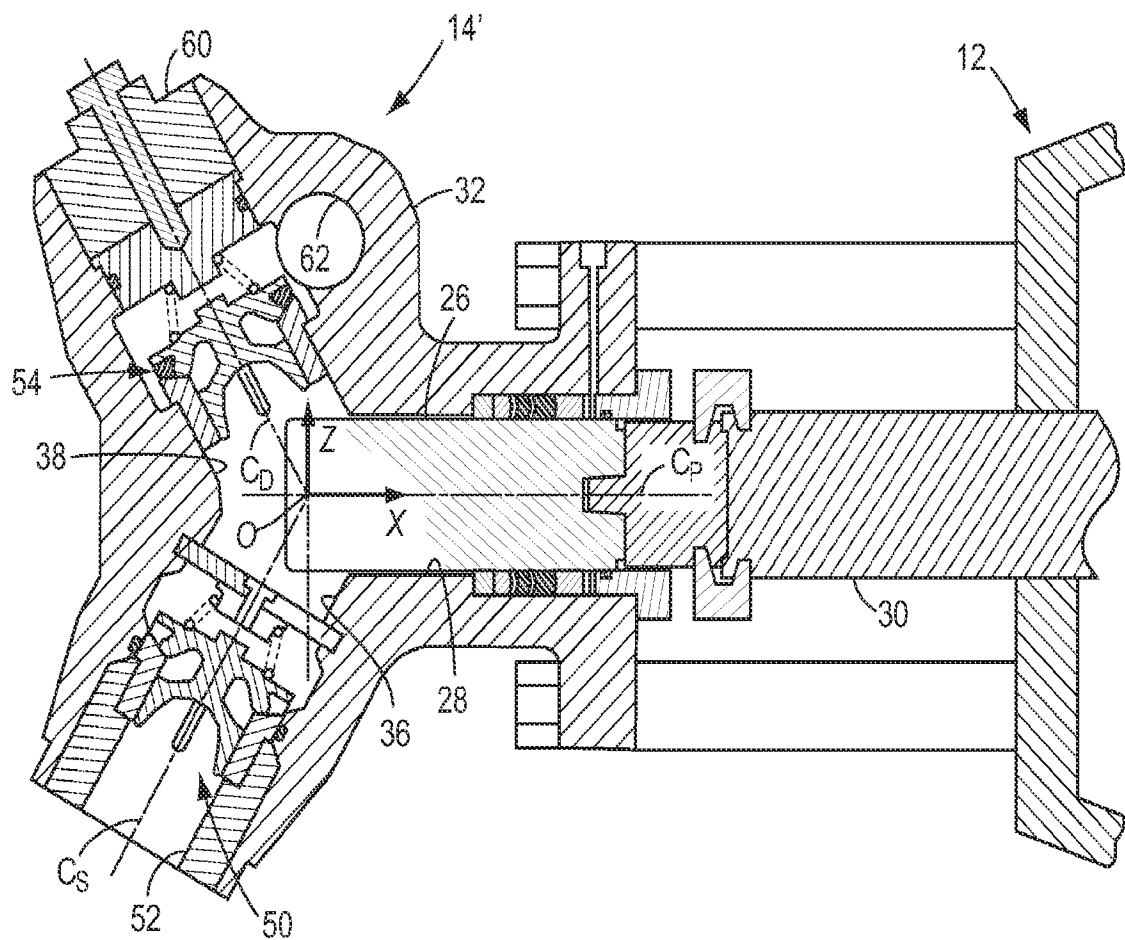


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 15/32300

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F04B 39/10 (2015.01)

CPC - F04B 39/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8): F04B 39/10 (2015.01)

CPC: F04B 39/10

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
 IPC(8): F16J 10/02, F16J 41/02, F16L 41/00 (2015.01) CPC: F16J 10/02, F04B 53/16, F04B 53/162, F04B 53/007, F16L 41/021, F04B 53/164, Y10T 137/7838, Y10T 137/0402, Y10T 29/49236, Y10T 29/49238 USPC: 417/56, 92/169.1, 137/15.01, 137/561

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatBase; ProQuest Dialog; Google Patents; Google Web; Google Scholar

Search Terms: crossbore%, cross bore%, cross-bore%, fluid end, "surface of revolution", sphere, spherical, ellipsoid, high pressure, chamber, curved, ball shaped, ball-shaped, conical, cone, piston, reciprocating, pump%, stress, crack, fatigue, corrosion, resist%

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2009/0041588 A1 (Hunter et al.). 12 February 2009 (12.02.2009). Figs. 1A-1D; para [0027].	1-20
A	US 2012/0141308 A1 (Saini et al.). 07 June 2012 (07.06.2012). Fig. 1; para [0023].	1-20
A	US 8,147,227 B1 (Blume). 03 April 2012 (03.04.2012). Fig. 7A; col 11, ln 41-43.	1-20
A	US 2012/0144995 A1 (Bayyounk et al.). 14 June 2012 (14.06.2012). Fig. 2; para [0053].	4-6, 11-13, 16-18
A, P	US 2014/0345452 A1 (Cary). 27 November 2014 (27.11.2014). Fig. 2E; para [0031].	1-20

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

27 July 2015 (27.07.2015)

Date of mailing of the international search report

19 AUG 2015

Name and mailing address of the ISA/US

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