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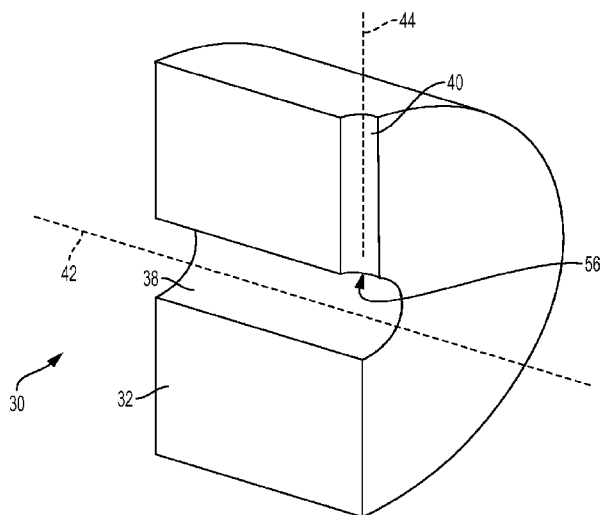


FIG. 3

(57) Abstract: A fuel accumulator is provided, comprising a body having a first end and a second end, a main bore extending along a longitudinal axis through the body between the first end and the second end, and a side drilling extending along an axis that is perpendicular to the longitudinal axis through the body and intersecting with the main bore. The main bore has an oval cross-section with a first dimension perpendicular to the axis of the side drilling and a second dimension parallel to the axis of the side drilling, the second dimension being less than the first dimension.



OVALIZED ROTARY FORGED FUEL SYSTEMS ACCUMULATOR

TECHNICAL FIELD

[0001] The present invention relates generally to fuel accumulators and more particularly to an ovalized rotary forged fuel accumulator that reduces stresses imparted to the accumulator as a result of pulsating high pressure fuel.

BACKGROUND

[0002] Various engines use common rail fuel accumulators which store fuel at a high pressure for use by the engine fuel injectors. The pulsations of the fuel pumps and of the injectors cause stress on surfaces of the common rail. Conventional common rails are cylindrical in shape, and include a cylindrical main bore that intersects cylindrical injector drillings. This configuration exhibit significant stress at the intersection between the main bore and the injector drillings.

[0003] One attempt to reduce the stress experienced by accumulators includes flattening one side of the main bore through the accumulator to induce compressive residual stresses at the intersection between the main bore and the cylindrical injector drillings. The corresponding deformation of the surfaces may, however, cause cracks that degrade the performance of the accumulator. Another approach includes machining the inner diameter of the main bore groove and using a radially offset intersecting fuel outlet bore. This approach has limitations when forming long bore lengths. Accordingly, there is a need to provide a common rail fuel accumulator having a geometry that exhibits reduced stress during operation.

SUMMARY

[0004] In one embodiment of the present disclosure, a fuel accumulator is provided, comprising: a body having a first end and a second end; a main bore extending along a longitudinal axis through the body between the first end and the second end; and a side drilling extending along an axis that is perpendicular to the longitudinal axis through the body and intersecting with the main bore. In this embodiment, the main bore has an oval cross-section with a first dimension perpendicular to the axis of the side drilling and a second dimension parallel to the axis of the side drilling, the second dimension being less than the first dimension.

In one aspect of this embodiment, the second dimension is approximately 75% of the first dimension. In another aspect, wherein the body has an oval cross-section with a first dimension perpendicular to the axis of the side drilling and a second dimension parallel to the axis of the side drilling, the second dimension being less than the first dimension. In a variant of this aspect, the second dimension of the main bore is less than the first dimension of the main bore by a first percentage and the second dimension of the body is less than the first dimension of the body by a second percentage, the first percentage being equal to the second percentage. In a further variant, the first percentage is approximately 75%. In another aspect, the body is formed of radially forged steel. Still another aspect includes a plurality of side drillings, each extending along an axis that is perpendicular to the longitudinal axis through the body and intersecting with the main bore.

[0005] According to another embodiment of the present disclosure, a method of forming a fuel accumulator is provided, comprising: obtaining a cylindrical piece of steel stock; drilling a bore through a longitudinal axis of the stock; inserting an oval-shaped mandrel into the bore; the oval-shaped mandrel having a first dimension perpendicular to a length of the oval-shaped mandrel that is larger than a second dimension perpendicular to the length of the oval-shaped mandrel and perpendicular to the first dimension; radially forging the stock with the oval-shaped mandrel inserted in the bore until the bore corresponds in shape to the oval-shaped mandrel; and removing the oval-shaped mandrel. In one aspect of this embodiment, the second dimension is approximately 75% of the first dimension. Another aspect further comprises radially forging the stock with the oval-shaped mandrel inserted in the bore until the stock becomes oval in shape with a first dimension perpendicular to the longitudinal axis of the stock that is larger than a second dimension perpendicular to the longitudinal axis of the stock and perpendicular to the first dimension. In a variant of this aspect, the second dimension of the bore is smaller than the first dimension by a first percentage and the second dimension of the stock is smaller than the first dimension of the stock by a second percentage which is equal to the first percentage. In a further variant, the first percentage is approximately 75%. Another aspect further comprises drilling side drillings into the stock perpendicular to the longitudinal axis, the side drillings intersecting the bore. A variant of this aspect further comprises treating the intersections between the side drillings and the bore. Another aspect comprises generating residual stress in the stock by at least one of autofrettage, nitriding, carburizing, and shot peening.

[0006] In yet another embodiment, a fuel system is provided, comprising: a fuel pump; a plurality of fuel injectors; and a fuel accumulator including a body having a first end and a second end, a main bore extending along a longitudinal axis through the body between the first end and the second end, the main bore being in fluid communication with the fuel pump, and a plurality of side drillings, each side drilling being in fluid communication with a fuel injector, extending along an axis that is perpendicular to the longitudinal axis through the body and intersecting with the main bore. In this embodiment, the main bore has an oval cross-section with a first dimension perpendicular to the side drilling axes and a second dimension parallel to the side drilling axes, the second dimension being less than the first dimension. In one aspect of this embodiment, the second dimension is approximately 75% of the first dimension. In another aspect, the body has an oval cross-section with a first dimension perpendicular to the side drilling axes and a second dimension parallel to the side drilling axes, the second dimension being less than the first dimension. In a variant of this aspect, the second dimension of the main bore is less than the first dimension of the main bore by a first percentage and the second dimension of the body is less than the first dimension of the body by a second percentage, the first percentage being equal to the second percentage. In another aspect, the body is formed of radially forged steel.

[0007] While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The above-mentioned and other features of this disclosure and the manner of obtaining them will become more apparent and the disclosure itself will be better understood by reference to the following description of embodiments of the present disclosure taken in conjunction with the accompanying drawings, wherein:

[0009] FIG. 1 is a perspective view of a prior art fuel accumulator;

[0010] FIG. 2A is a perspective view of a fuel accumulator according to one embodiment of the present disclosure;

- [0011]** FIG. 2B is a cross-sectional view of the fuel accumulator of FIG. 2A taken along line B-B;
- [0012]** FIG. 2C is a cross-sectional view of the fuel accumulator of FIG. 2A taken along line A-A;
- [0013]** FIG. 3 is a cross-sectional view of a portion of the fuel accumulator of FIG. 2A;
- [0014]** FIG. 4 is a simulation view of the fuel accumulator of FIG. 2A using a first geometry;
- [0015]** FIG. 5 is a simulation view of the fuel accumulator of FIG. 2A using a second geometry;
- [0016]** FIG. 6 is a simulation view of the fuel accumulator of FIG. 2A using a third geometry;
- [0017]** FIG. 7 is a chart showing simulation data for various geometries of fuel accumulators; and
- [0018]** FIG. 8 is a flow diagram of a method for radially forging an accumulator according to the present disclosure.
- [0019]** While the present disclosure is amenable to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and are described in detail below. The present disclosure, however, is not to limit the particular embodiments described. On the contrary, the present disclosure is intended to cover all modifications, equivalents, and alternatives falling within the scope of the appended claims.

DETAILED DESCRIPTION

[0020] Referring now to FIG. 1, a conventional fuel accumulator 10 is shown having a body 12 typically made of high strength steel and having a first end 16 and a second end 18. Between the ends 16, 18 of accumulator 10 a main bore 14 is typically formed which extends coaxially with the longitudinal axis of the accumulator 10. Main bore 14 is typically terminated with drillings (not shown) that permit connection of main bore 14 with a fueling system (not shown). A plurality of injector or side drillings 20 are formed into body 12 of accumulator 10 to intersect with (typically perpendicular with) main bore 14. As will be understood by those skilled in the art, each of the side drillings 20 is coupled to a fuel injector (not shown) which provides high pressure fuel to a corresponding cylinder of the engine. As will be also understood

by those skilled in the art, each of main bore 14 and injector drillings 20 are typically formed to have a circular cross-section, such as by conventional drilling. The intersection of the side drillings 20 with the main bore 14, however, results in high stress as a result of continuous pulsations of the fuel pump and the fuel injectors as is further described below.

[0021] Accordingly, the present disclosure provides a modified intersection between the side drillings 20 and main bore 14, as well as a modified shape of body 12. Referring now to FIG. 2A, a portion of a fuel accumulator 30 according to the present disclosure is shown. Accumulator 30 includes a body 32 having a first end 34 and a second end 36, and a main bore 38 that extends between the ends 34, 36. A plurality of side drillings 40 (only one shown) extend through body 32 and intersect with main bore 38. As a result of the forming method described herein, body 32 and main bore 38 are oval in cross-section, which results in lower stress in the intersections between side drillings 40 and main bore 38.

[0022] FIG. 2B shows a cross-sectional view of accumulator 30 taken along line B-B of FIG. 2A. In one embodiment of the present disclosure, main bore 38 through body 32 has a longitudinal axis 42 that is substantially perpendicular to a longitudinal axis 44 of side drillings 40. As is further described below, a typical dimension of the diameter 46 of side drillings 40 is approximately 4 mm. However, side drillings 40 of a smaller or larger diameter may also be used according to the principles of the present disclosure.

[0023] FIG. 2C shows a cross-sectional view of accumulator 30 taken along line A-A of FIG. 2A. As shown, body 32 of accumulator 30 is oval in cross-section, having a larger dimension 48 ("dimension A") and a smaller dimension 50 ("dimension B"). Similarly, main bore 38 is also oval in cross-section and has a larger dimension 52 ("dimension a") and a smaller dimension 54 (dimension b). The ratio of dimension B to dimension A and dimension b to dimension a is selected to provide reduced stress at the intersections between side drillings 40 and main bore 38 as is further described below.

[0024] Referring now to FIG. 8, a method for forming fuel accumulator 30 having an oval-shaped body 32 and main bore 38 is shown. At step 92, a cylindrical piece of steel (e.g., round bar stock) or other suitable material is obtained. The stock is either obtained having an appropriate diameter and length or drawn to an appropriate diameter and length. At step 94 a main bore is formed such as by gun drilling through the longitudinal axis of the stock. Next, at step 96, an oval-shaped, hard mandrel having approximately the dimensions 52, 54 of main bore

38 is placed into the bore formed through body 32 of the stock. With the mandrel in place, at step 98 the stock is pounded or forged in a radial direction around the mandrel. The round bar stock and main bore are thus forged into a stress-improved oval geometry. Other features of accumulator 30 may also be forged at step 98 such as flats, ports, etc. The mandrel is then removed at step 100, and side drillings 40 are drilled into body 32 at step 102 in a conventional manner.

[0025] Further processing may be used to complete accumulator 30. For example, the ends 34, 36 of main bore 38 may be counter-bore drilled and tapped to form threaded circular bores to allow attachment of end fittings. Additionally, as indicated by step 104 of FIG. 8, the intersections between side drillings 40 and main bore 38 may be treated to eliminate sharp edges such as by thermal deburring, electrochemical deburring and/or abrasive flow machining. Also, at step 106 accumulator 30 may be treated to generate residual stress to increase the fatigue resistance of internal geometries such as by autofrettage (e.g., impart compressive residual stress with one time very high internal pressure), nitriding, carburizing, or shot peening.

[0026] The oval shape of body 32 and main bore 38 provides stress reduction in accumulator 30 as is further described herein. In an alternate embodiment, body 32 may be circular in cross-section, while main bore 28 remains oval in cross-section. The oval shape of main bore 38 results in an elongated saddle-shaped intersection between main bore 38 and side drillings 40. This elongated intersection allows the forces caused by the internal fuel pressure to be spread out over a larger area. As is known in the art, stress may be measured as force / area, and therefore an increase in area results in reduced stress for a constant force. Lower peak stresses at the bore intersections may result in a more robust fuel system accumulator 30.

[0027] Referring now to FIG. 3, accumulator 30 is shown sectioned along longitudinal axis 42 of main bore 38 and perpendicular to longitudinal axis 42 of main bore 38 through axis 44 of side drilling 40. This sectioning exposes one-fourth of the saddle shaped intersection 56 between main bore 38 and side drilling 40. The quarter model depicted in FIG. 3 was the subject of a Finite Element Analysis to determine a desirable ratio between the large diameter 52 (dimension a) of main bore 38 and the small diameter 54 (dimension b) of main bore 38 (FIG. 2C).

[0028] Referring now to FIG. 4, a baseline simulation result is shown for the quarter model of FIG. 3 when dimension b of main bore 38 equals dimension a of main bore 38 (note

also that body 32 is circular in cross-section such that dimension B of body 32 equals dimension A of body 32). As shown, the location of maximum stress on accumulator 30 is at the high point 58 of intersection 56. Point 58 may experience the most stretching as a result of fuel pulsations from operation of the fuel pump and the fuel injectors.

[0029] In the simulation of FIG. 5, small dimensions of both body 32 and main bore 38 (i.e., dimension B and dimension b, respectively) have been reduced to 75% of the corresponding large dimensions of body 32 and main bore 38. The location of maximum stress on accumulator 30 is still at high point 58 of intersection 56, but the amount of stress is reduced by approximately 32% as compared to the simulation of the round body 32 and main bore 38 of FIG. 4.

[0030] Referring now to FIG. 6, a simulation of the quarter model of FIG. 3 is shown wherein the small dimensions of body 32 and main bore 38 are 55% of the corresponding large dimensions of body 32 and main bore 38. It should be noted that for this geometry, the location of maximum stress is no longer at high point 58. Instead, the model shows the maximum stress location is along the apex 60 of main bore 38.

[0031] The chart 62 of FIG. 7 shows simulation results for a variety of ratios of large/small dimensions of body 32 and main bore 38, including the ratios discussed above with reference to FIGs. 4-6. As shown, row 64 of table 62 includes the baseline results discussed above with reference to FIG. 4 wherein body 32 and main bore 38 are round. Columns 66, 68 show that both dimension A and dimension B of body 32 were 20 mm. Columns 70, 72 show that dimension a and dimension b of main body 38 were 4 mm. As shown in column 74, 2800 bar internal pressure was used in the simulations. As shown in column 76, the maximum stress for the model geometries decreased from the baseline results of row 64 to the results of row 78 which corresponds to the geometry depicted in FIG. 5 and discussed above wherein dimension B of body 32 and dimension b of man bore 38 are 75% of the corresponding larger dimensions. Column 76 also shows that as the smaller dimensions of body 32 and main bore 38 were further reduced relative to the larger dimensions, the maximum stress increased. The results of the geometry of FIG. 6 discussed above are shown in row 80. Finally, column 82 shows that from the baseline results of row 64 to the results of row 78, the location of maximum stress was at high point 58 of the bore intersection 56. However, for geometries having more ovalized bodies and main bores (i.e., simulation results below row 78), the location of maximum stress was along

the apex 60 of main bore 38. Accordingly, the lowest stress geometry depicted in table 62 is that having the 75% ratio as shown in row 78. However, other geometries may be useful in reducing the stress experienced by accumulator 30 such as those having ratios of approximately 75% (i.e., ratios in the range of 78% and 72%). Other geometries may also be used.

[0032] Various modifications and additions can be made to the exemplary embodiments discussed without departing from the scope of the present invention. For example, while the embodiments described above refer to particular features, the scope of this invention also includes embodiments having different combinations of features and embodiments that do not include all of the described features. Accordingly, the scope of the present invention is intended to embrace all such alternatives, modifications, and variations as fall within the scope of the claims, together with all equivalents thereof.

CLAIMS

We claim:

1. A fuel accumulator, comprising:
 - a body having a first end and a second end;
 - a main bore extending along a longitudinal axis through the body between the first end and the second end; and
 - a side drilling extending along an axis that is perpendicular to the longitudinal axis through the body and intersecting with the main bore;wherein the main bore has an oval cross-section with a first dimension perpendicular to the axis of the side drilling and a second dimension parallel to the axis of the side drilling, the second dimension being less than the first dimension.
2. The fuel accumulator of claim 1, wherein the second dimension is approximately 75% of the first dimension.
3. The fuel accumulator of claim 1, wherein the body has an oval cross-section with a first dimension perpendicular to the axis of the side drilling and a second dimension parallel to the axis of the side drilling, the second dimension being less than the first dimension.
4. The fuel accumulator of claim 3, wherein the second dimension of the main bore is less than the first dimension of the main bore by a first percentage and the second dimension of the body is less than the first dimension of the body by a second percentage, the first percentage being equal to the second percentage.
5. The fuel accumulator of claim 4, wherein the first percentage is approximately 75%.
6. The fuel accumulator of claim 1, wherein the body is formed of radially forged steel.
7. The fuel accumulator of claim 1, including a plurality of side drillings, each extending along an axis that is perpendicular to the longitudinal axis through the body and intersecting with the main bore.

8. A method of forming a fuel accumulator, comprising:
 - obtaining a cylindrical piece of steel stock;
 - drilling a bore through a longitudinal axis of the stock;
 - inserting an oval-shaped mandrel into the bore; the oval-shaped mandrel having a first dimension perpendicular to a length of the oval-shaped mandrel that is larger than a second dimension perpendicular to the length of the oval-shaped mandrel and perpendicular to the first dimension;
 - radially forging the stock with the oval-shaped mandrel inserted in the bore until the bore corresponds in shape to the oval-shaped mandrel; and
 - removing the oval-shaped mandrel.
9. The method of claim 8, wherein the second dimension is approximately 75% of the first dimension.
10. The method of claim 8, further comprising radially forging the stock with the oval-shaped mandrel inserted in the bore until the stock becomes oval in shape with a first dimension perpendicular to the longitudinal axis of the stock that is larger than a second dimension perpendicular to the longitudinal axis of the stock and perpendicular to the first dimension.
11. The method of claim 10, wherein the second dimension of the bore is smaller than the first dimension by a first percentage and the second dimension of the stock is smaller than the first dimension of the stock by a second percentage which is equal to the first percentage.
12. The method of claim 11, wherein the first percentage is approximately 75%.
13. The method of claim 8, further comprising drilling side drillings into the stock perpendicular to the longitudinal axis, the side drillings intersecting the bore.
14. The method of claim 13, further comprising treating the intersections between the side drillings and the bore.

15. The method of claim 8, further comprising generating residual stress in the stock by at least one of autofrettage, nitriding, carburizing, and shot peening.
16. A fuel system, comprising:
a fuel pump;
a plurality of fuel injectors; and
a fuel accumulator including
a body having a first end and a second end,
a main bore extending along a longitudinal axis through the body between the first end and the second end, the main bore being in fluid communication with the fuel pump, and
a plurality of side drillings, each side drilling being in fluid communication with a fuel injector, extending along an axis that is perpendicular to the longitudinal axis through the body and intersecting with the main bore;
wherein the main bore has an oval cross-section with a first dimension perpendicular to the side drilling axes and a second dimension parallel to the side drilling axes, the second dimension being less than the first dimension.
17. The fuel system of claim 16, wherein the second dimension is approximately 75% of the first dimension.
18. The fuel system of claim 16, wherein the body has an oval cross-section with a first dimension perpendicular to the side drilling axes and a second dimension parallel to the side drilling axes, the second dimension being less than the first dimension.
19. The fuel system of claim 18, wherein the second dimension of the main bore is less than the first dimension of the main bore by a first percentage and the second dimension of the body is less than the first dimension of the body by a second percentage, the first percentage being equal to the second percentage.
20. The fuel system of claim 16, wherein the body is formed of radially forged steel.

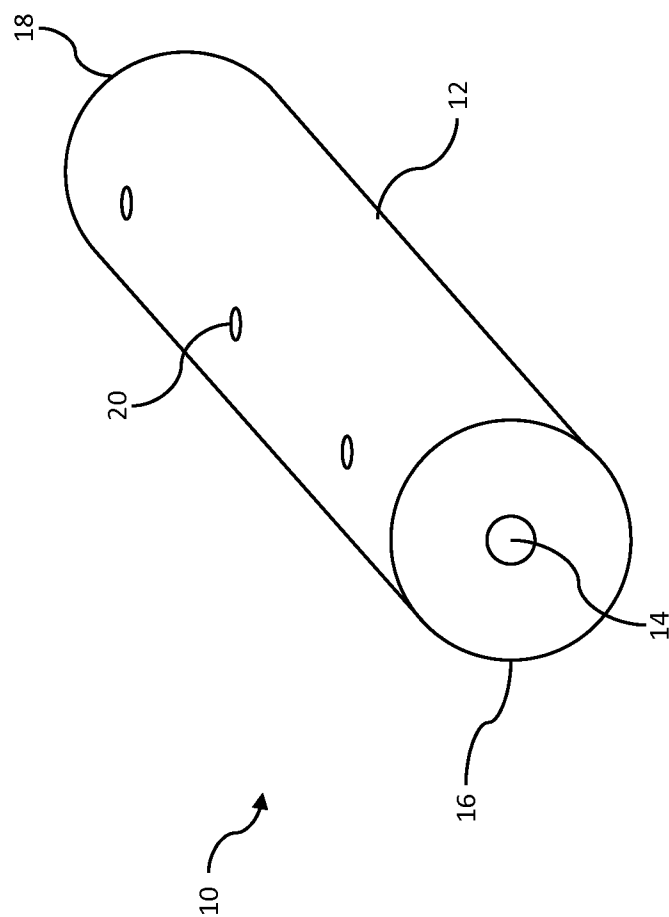


FIGURE 1 – PRIOR ART

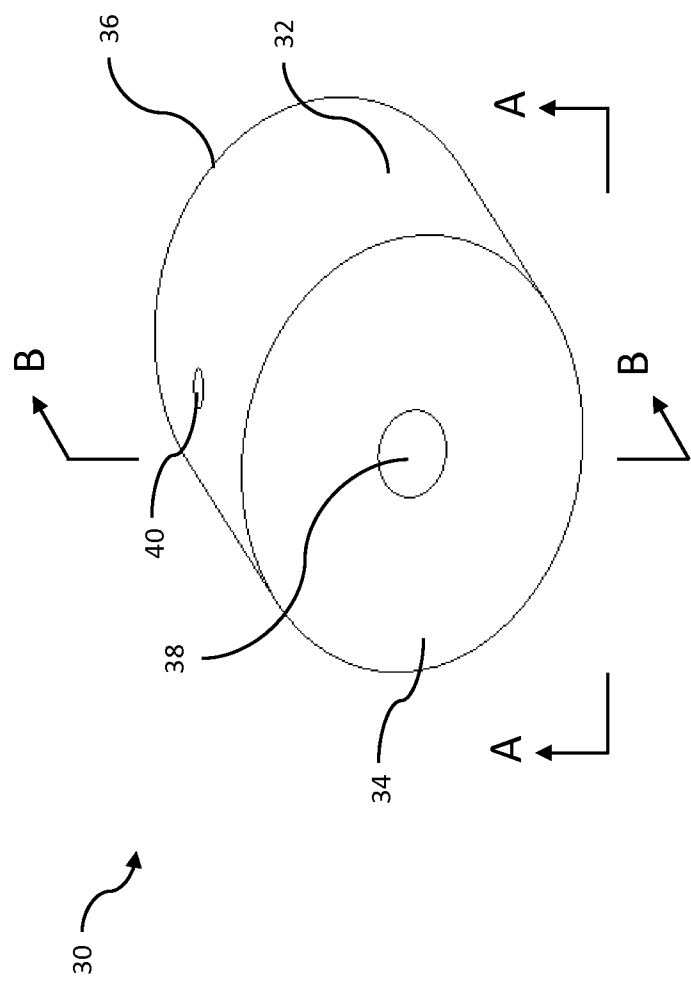


FIGURE 2A

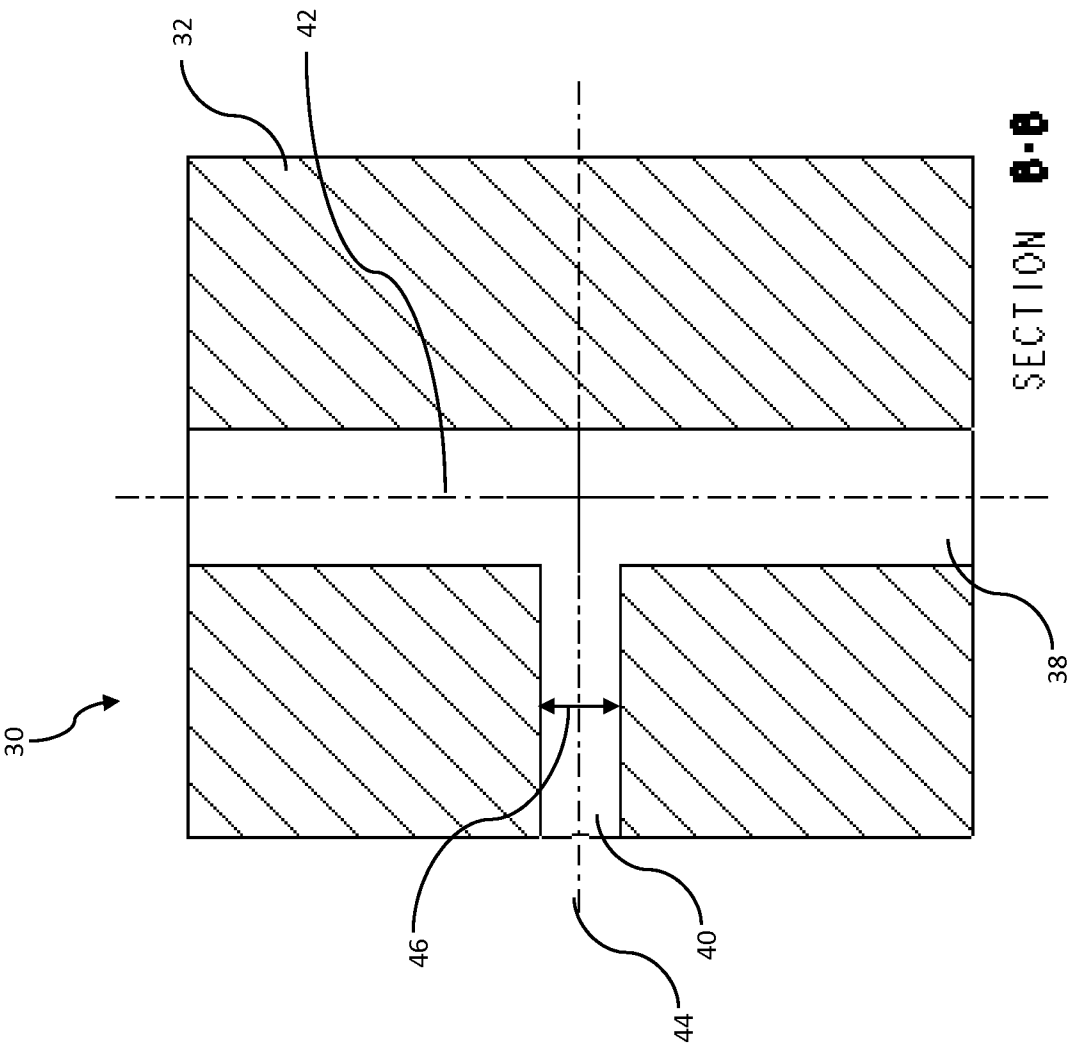


FIGURE 2B

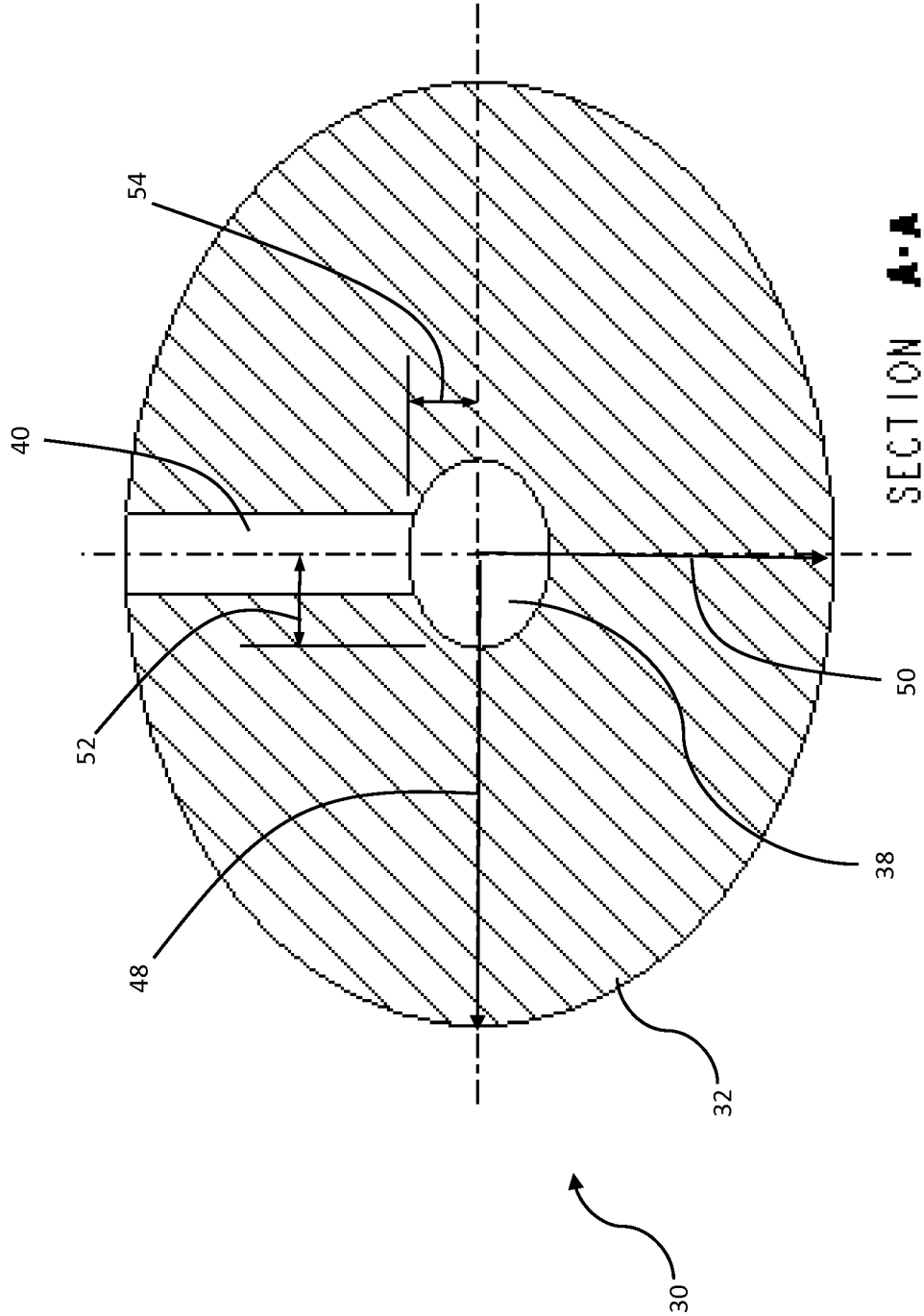


FIGURE 2C

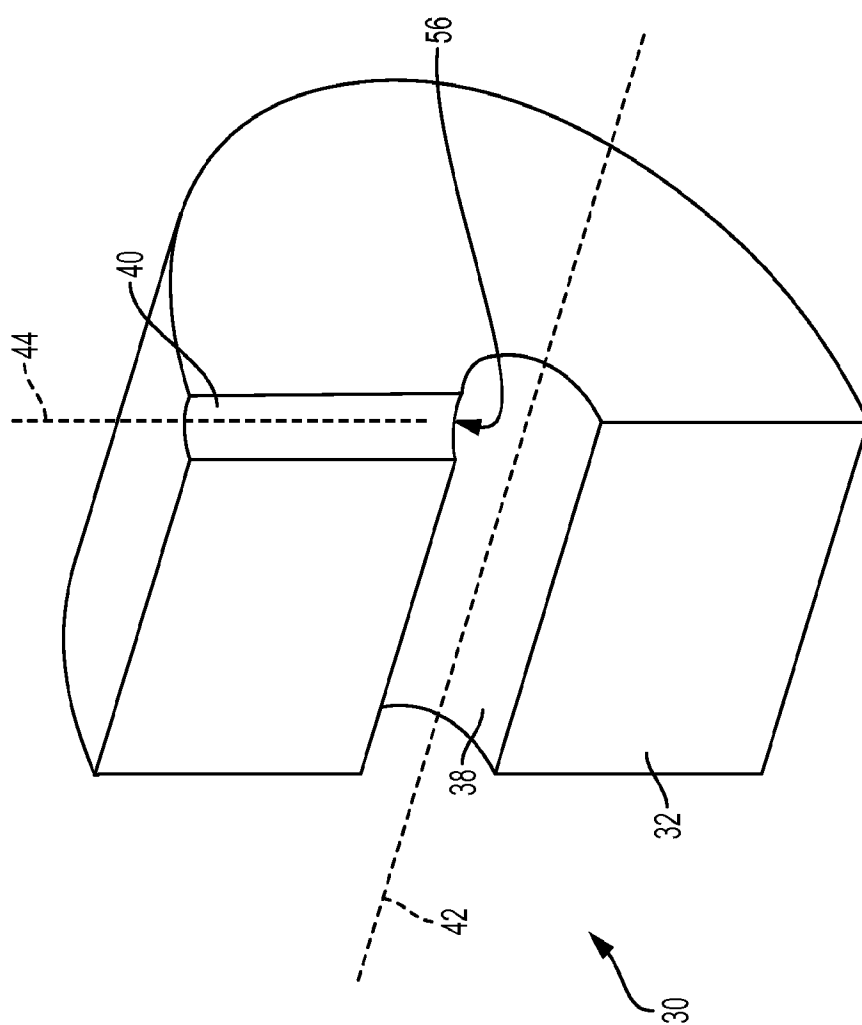
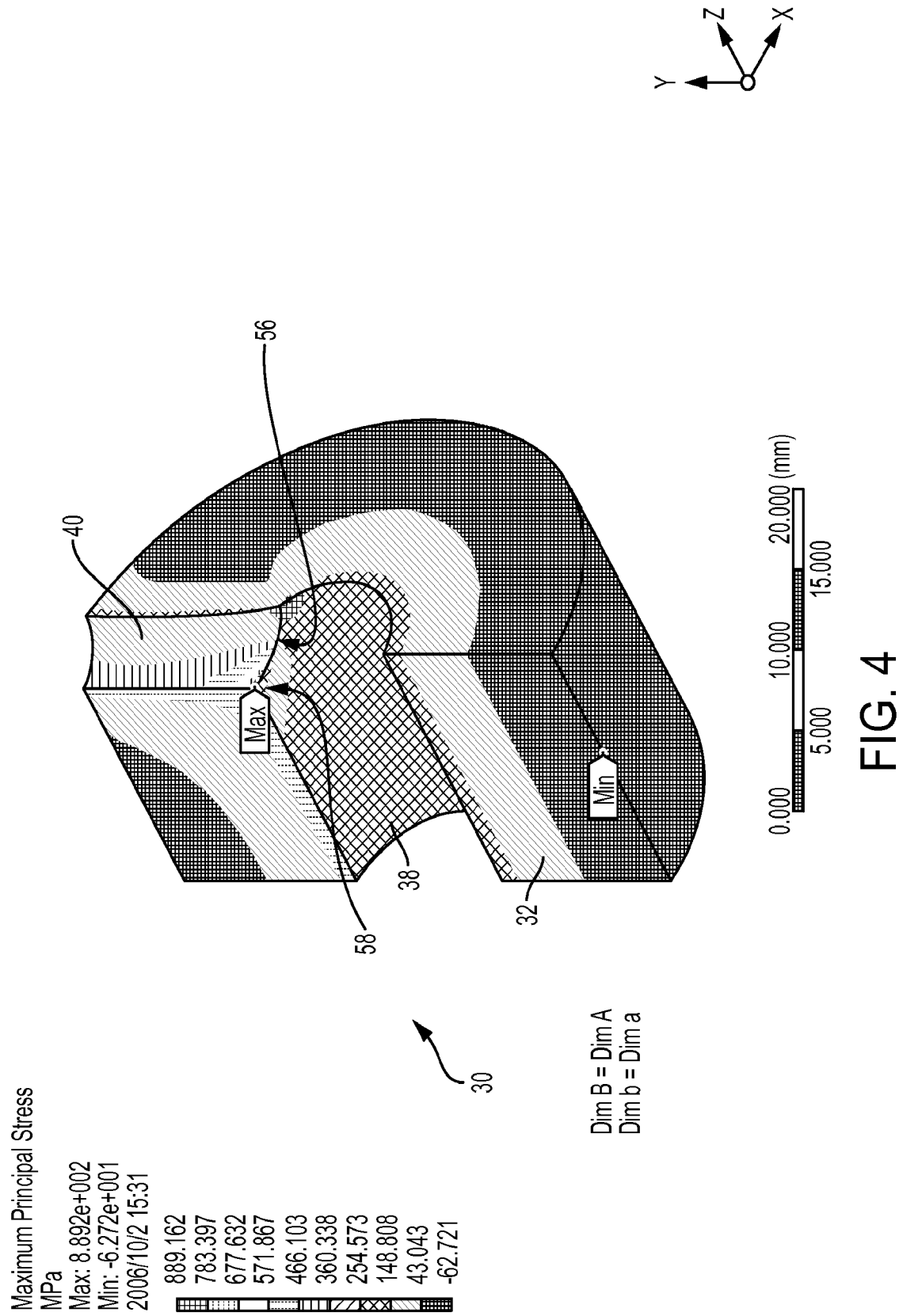
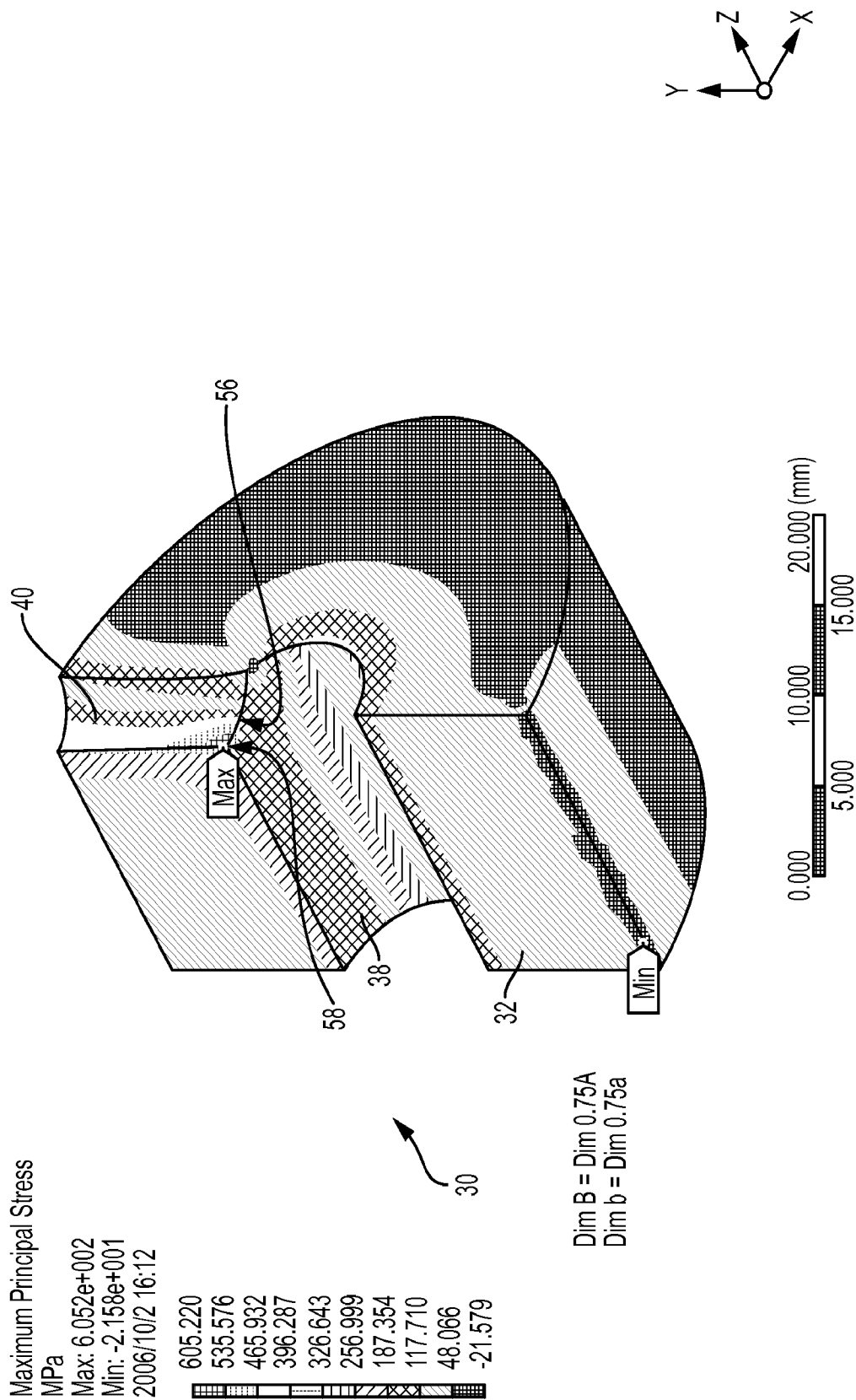


FIG. 3





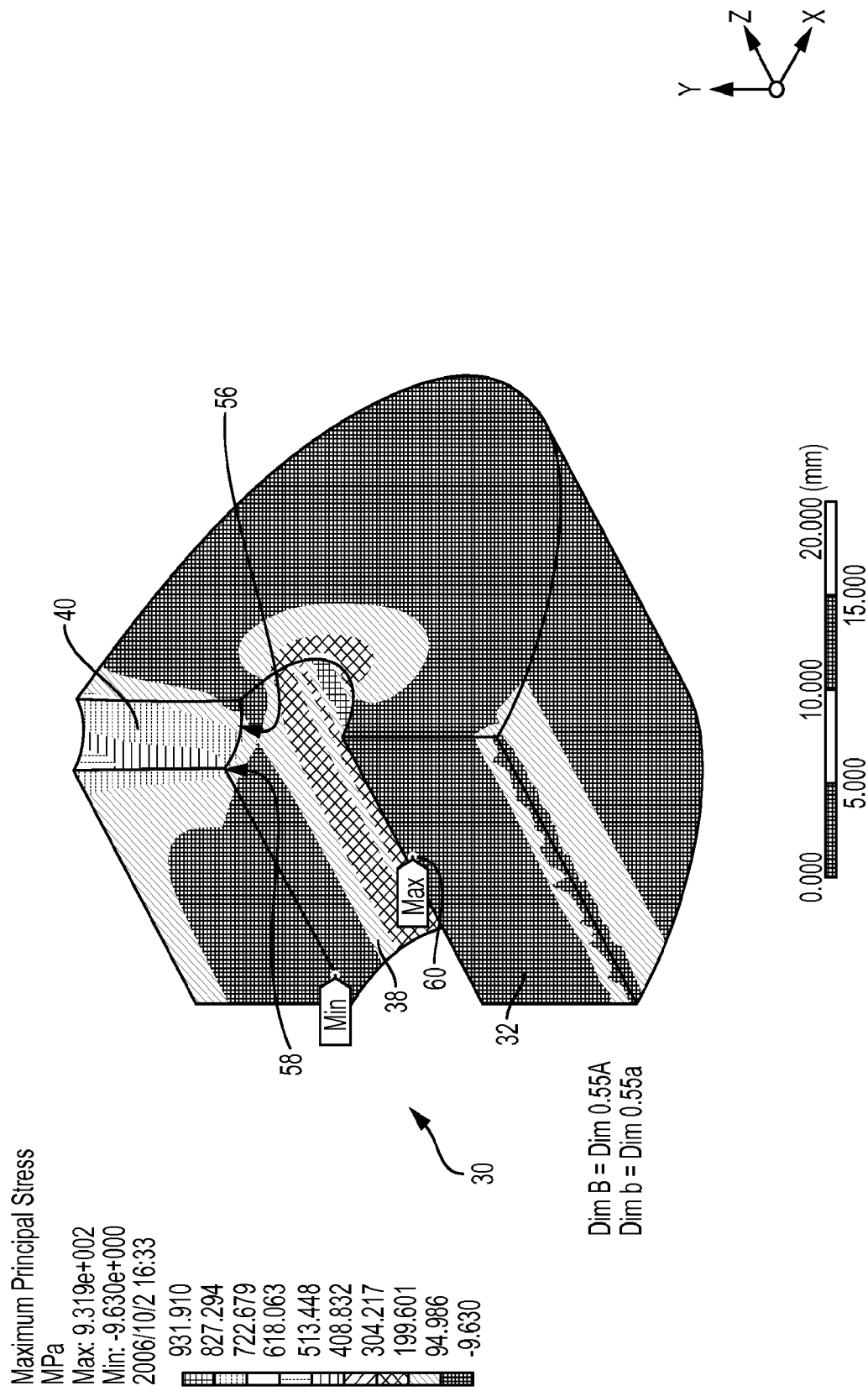


FIG. 6

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Fuel Rail Peak Stresses versus Geometry

Rail Geometry	Body Dimensions		Main Bore Dimensions				Outlet Bore ID (mm)	Main Bore Flow Area (mm ²)	Rail Body X-section Area (mm ²)	Internal Pressure (bar)	High Max Principle Stress (MPa)	Location of High Max Principle Stress
	Dim "A" (mm)	Dim "B" (mm)	Dim "a" (mm)	Dim "b" (mm)								
Round-Baseline B = 1.00A	20	20	4	4			4	50.27	1206.37	2800	889	Bore Intersection
Oval B = 0.95A	20.5196	19.4936	4.1039	3.8987			4	50.27	1206.37	2800	834	Bore Intersection
Oval B = 0.90A	21.0819	18.9737	4.2164	3.7947			4	50.27	1206.37	2800	777	Bore Intersection
Oval B = 0.85A	21.6930	18.4391	4.3386	3.6878			4	50.27	1206.37	2800	717	Bore Intersection
Oval B = 0.80A	22.3607	17.8885	4.4721	3.5777			4	50.27	1206.37	2800	660	Bore Intersection
Oval B = 0.75A	23.0940	17.3205	4.6188	3.4641			4	50.27	1206.37	2800	605	Bore Intersection
Oval B = 0.70A	23.9046	16.7332	4.7809	3.3466			4	50.27	1206.37	2800	616	Main Bore
Oval B = 0.65A	24.8069	16.1245	4.9614	3.2249			4	50.27	1206.37	2800	703	Main Bore
Oval B = 0.60A	25.8199	15.4919	5.1640	3.0984			4	50.27	1206.37	2800	806	Main Bore
Oval B = 0.55A	26.9680	14.8324	5.3936	2.9665			4	50.27	1206.37	2800	932	Main Bore
Oval B = 0.50A	28.2843	14.1421	5.6569	2.8284			4	50.27	1206.37	2800	1094	Main Bore

66

68

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72

74

76

82

FIG. 7

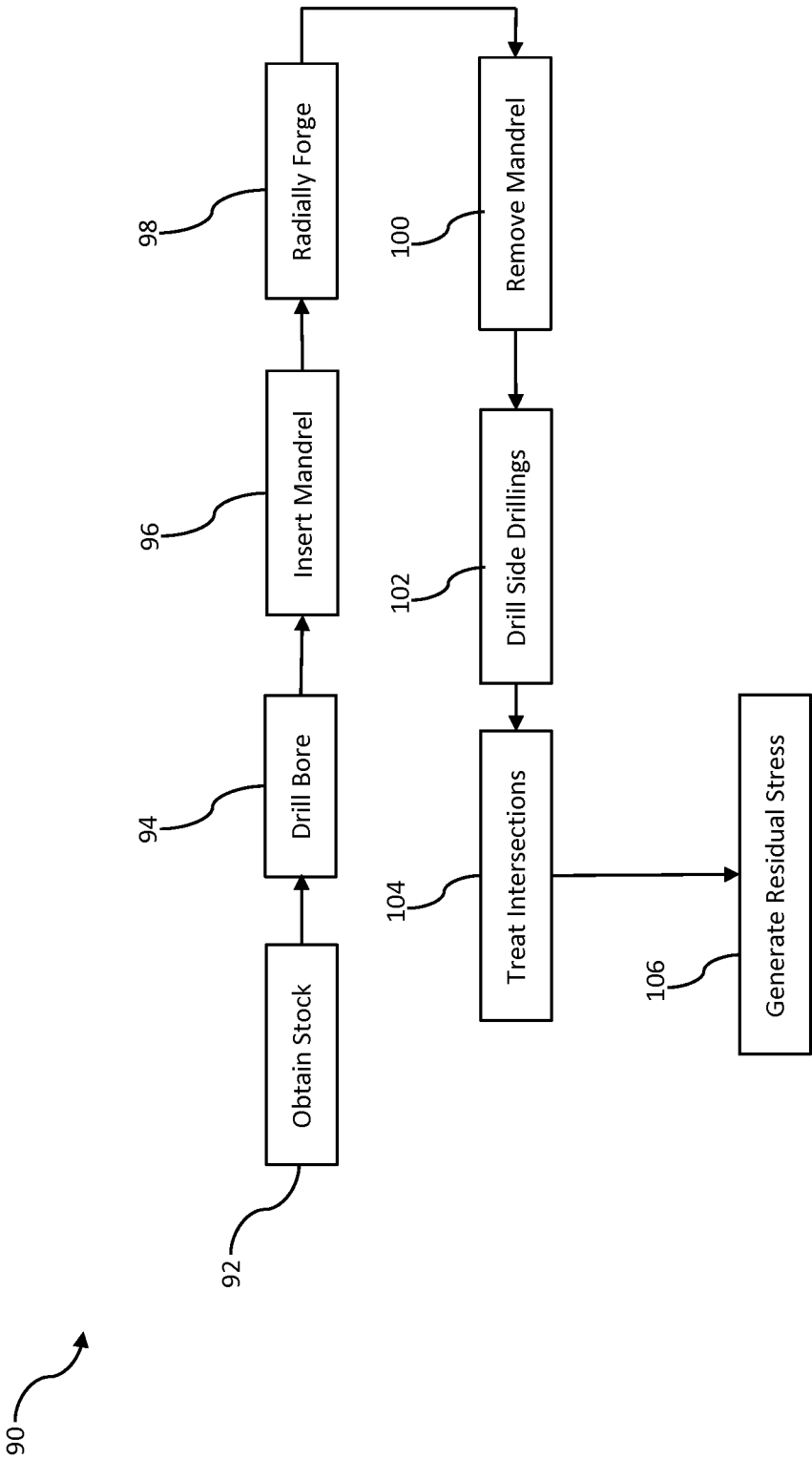


FIGURE 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/022953

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02M55/02
ADD.

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)
B21C B21D B21K F02M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 101 40 058 A1 (BOSCH GMBH ROBERT [DE]) 24 October 2002 (2002-10-24) paragraphs [0001], [0009] - [0010], [0020] - [0032] figures 1,2,3b -----	1-4,7, 16-20
X	WO 2004/069446 A1 (BOSCH GMBH ROBERT [DE]; DEGN MARKUS [AT]; RAHN THOMAS [AT]) 19 August 2004 (2004-08-19) pages 2,4-9 figure 5 -----	1,2,6-20
X	EP 1 076 172 A2 (WINKELMANN & PANNHOFF GMBH [DE]) 14 February 2001 (2001-02-14) paragraphs [0024], [0039] pages 8,9 ----- -/-	1-3,5-7, 16-18,20



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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)

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"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

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