US 20040118562A1

(19) **United States**
(12) **Patent Application Publication**
(10) **Pub. No.: US 2004/0118562 A1**
(43) **Pub. Date: Jun. 24, 2004**

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(54) **RETRIEVABLE MULTI-PRESSURE CYCLE FIRING HEAD**

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(21) Appl. No.: **10/325,079**

(22) Filed: **Dec. 20, 2002**

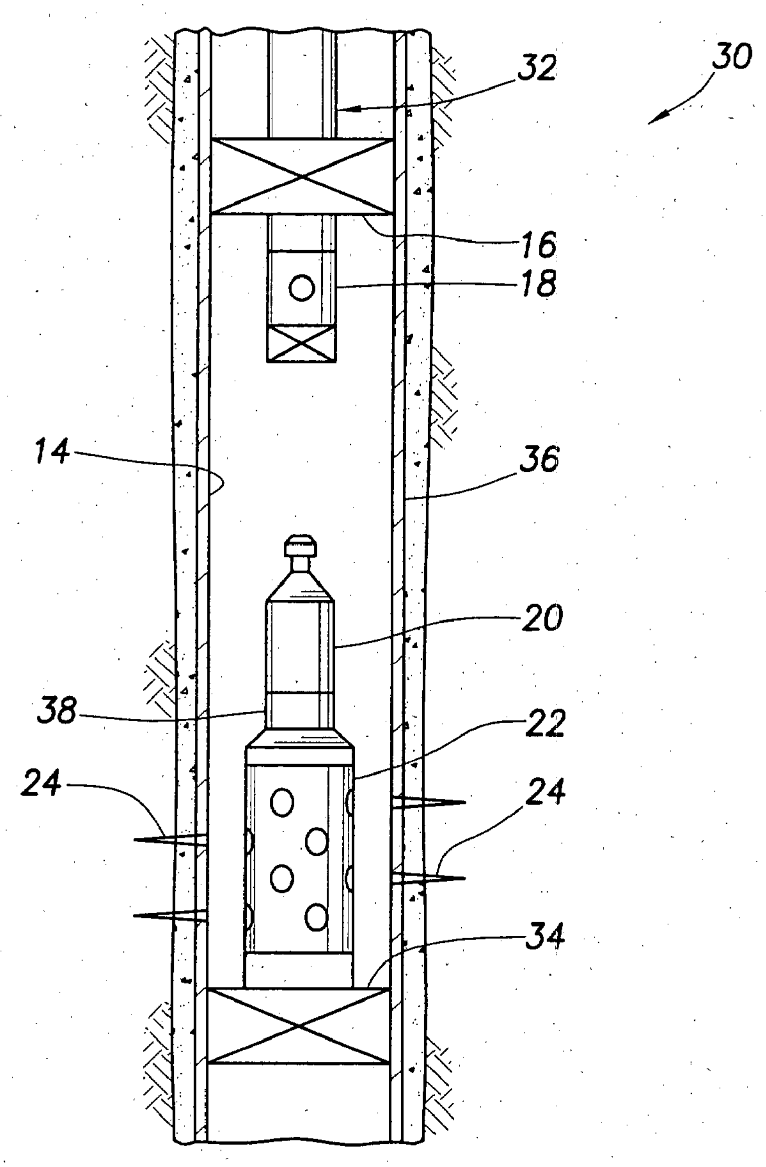
Publication Classification

(51) **Int. Cl.**^{7} **E21B 29/00**; E21B 43/11

(52) **U.S. Cl.** **166/297**; 175/4.55

(57) **ABSTRACT**

A multi-cycle pressure operated firing head for use in a subterranean well. In a described embodiment, a pressure actuated firing head for detonating a perforating gun in a subterranean well includes a firing mechanism and a member which displaces incrementally in response to alternating pressure increases and decreases applied to the firing head. The firing mechanism fires when the member displaces a predetermined distance. In another embodiment, a firing head includes a firing mechanism and a displacement mechanism which displaces a member of the firing head in response to a decrease in a pressure level proximate the firing head in the well. The firing mechanism fires when the member is displaced by the displacement mechanism.



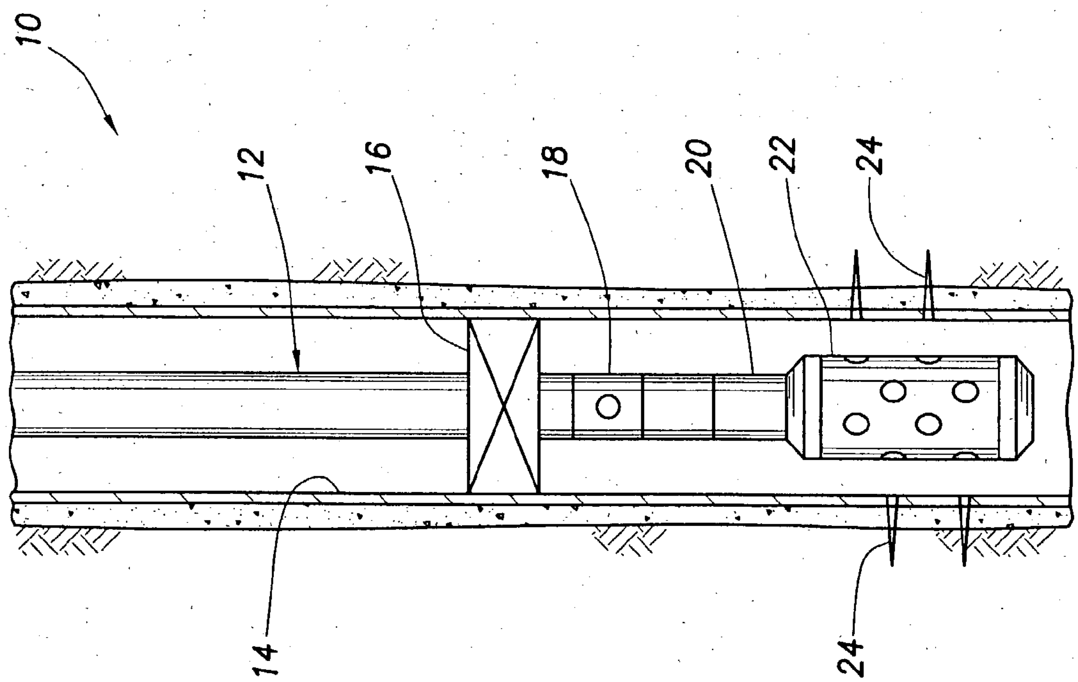


FIG.1

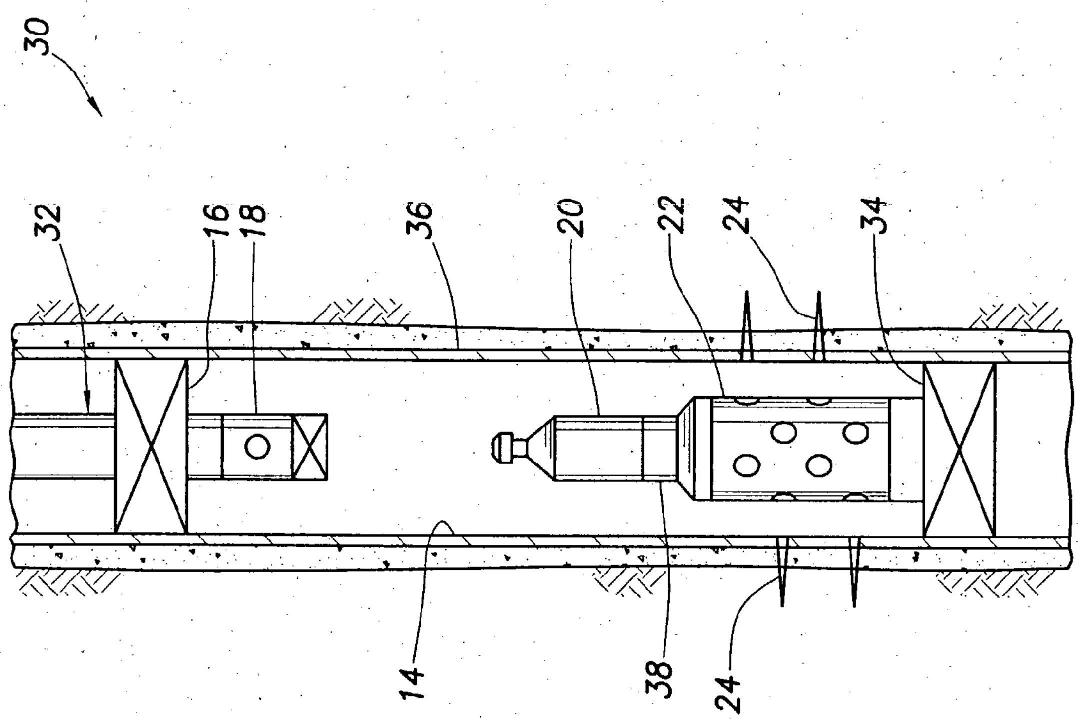


FIG.2

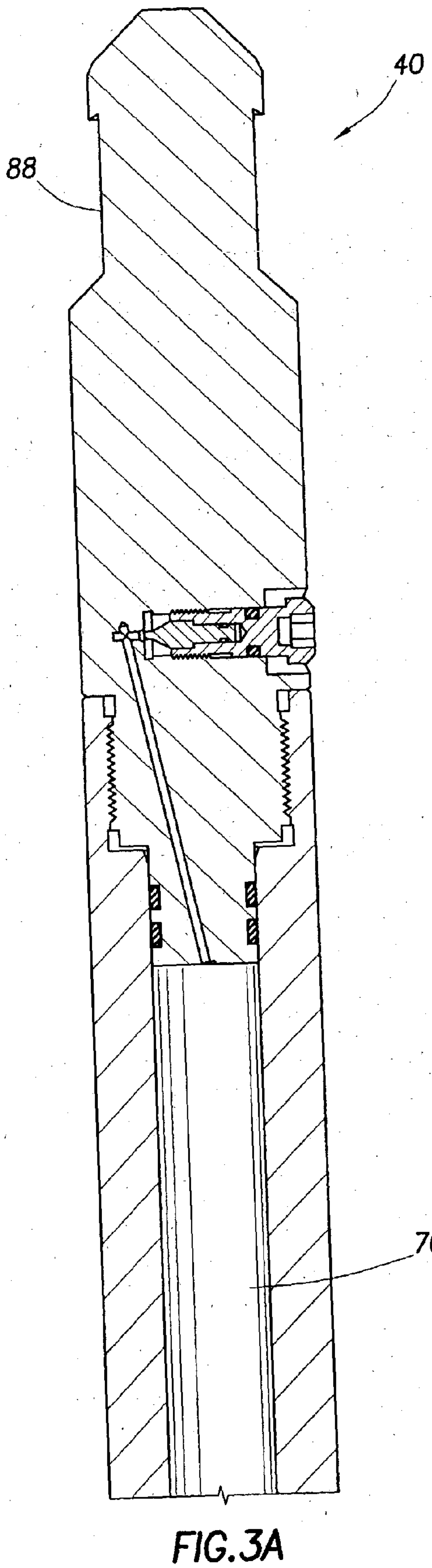


FIG.3A

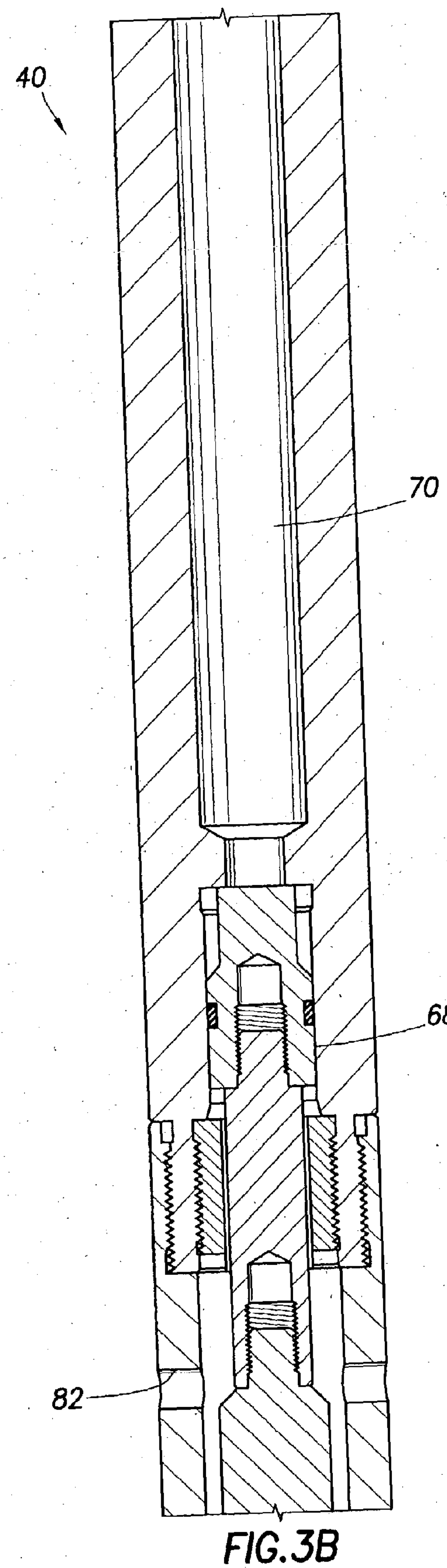


FIG.3B

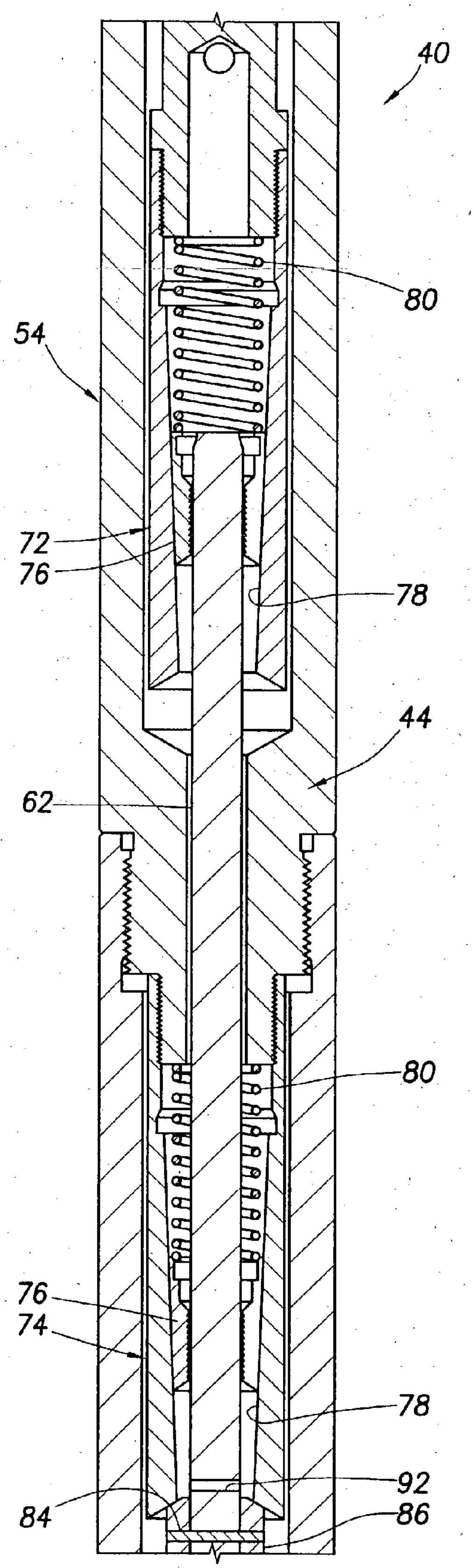

40
54
80
72
76
78
44
62
80
76
74
78
92
84
86

FIG.3C

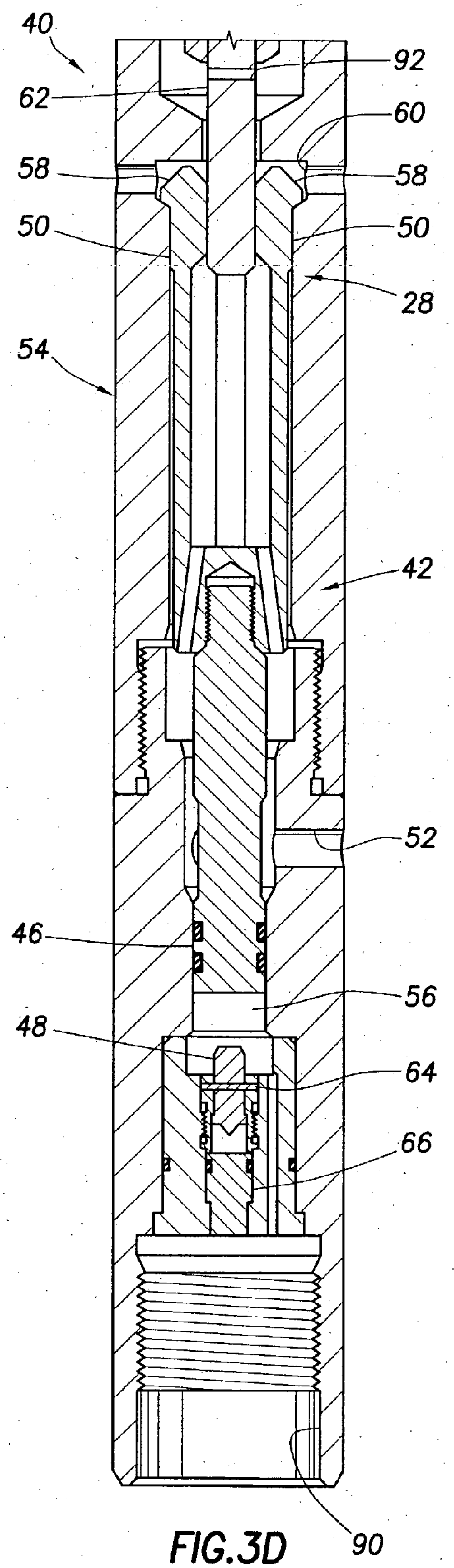

40
92
62
60
58
58
50
50
28
54
42
52
46
56
48
64
66
90

FIG.3D

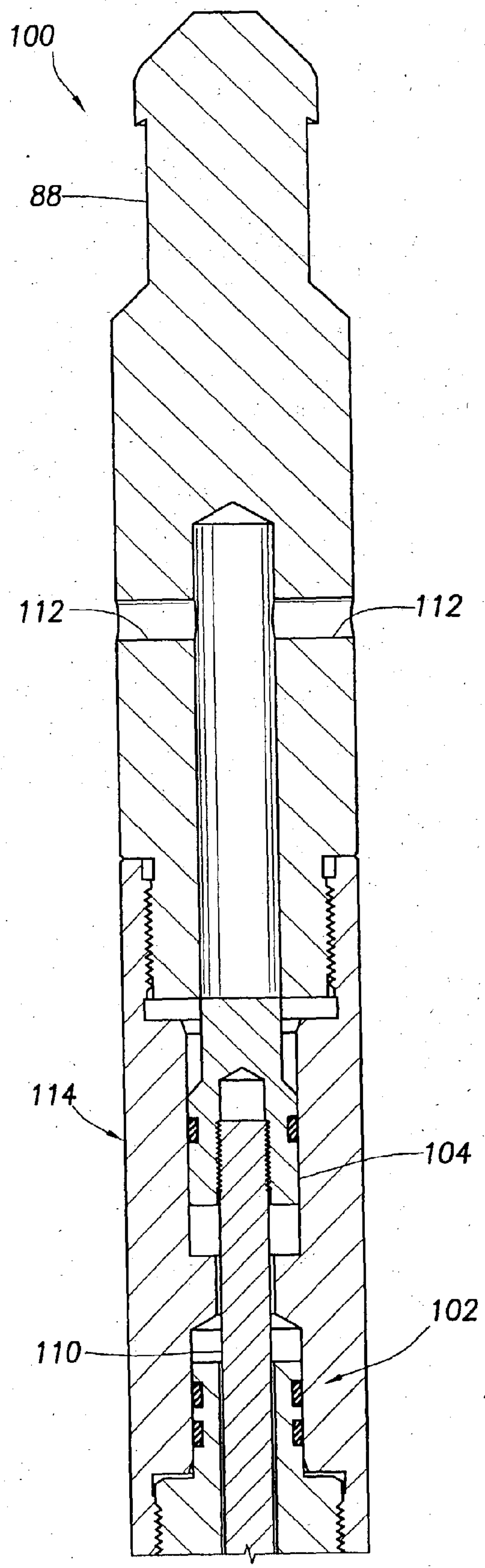


FIG.4A

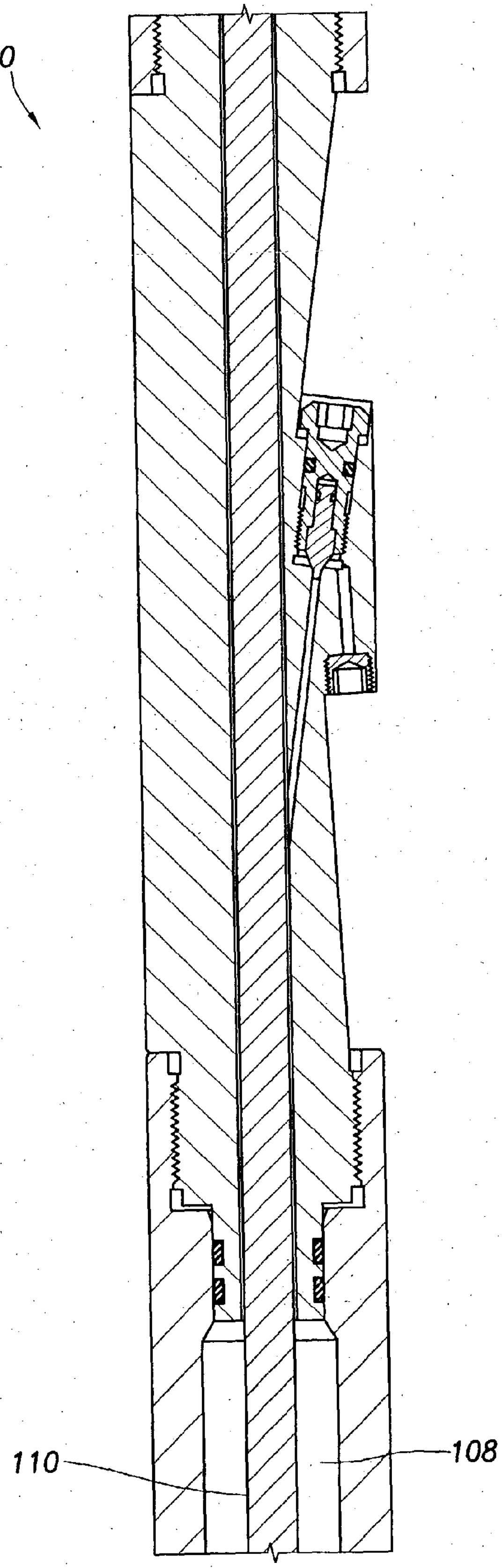


FIG.4B

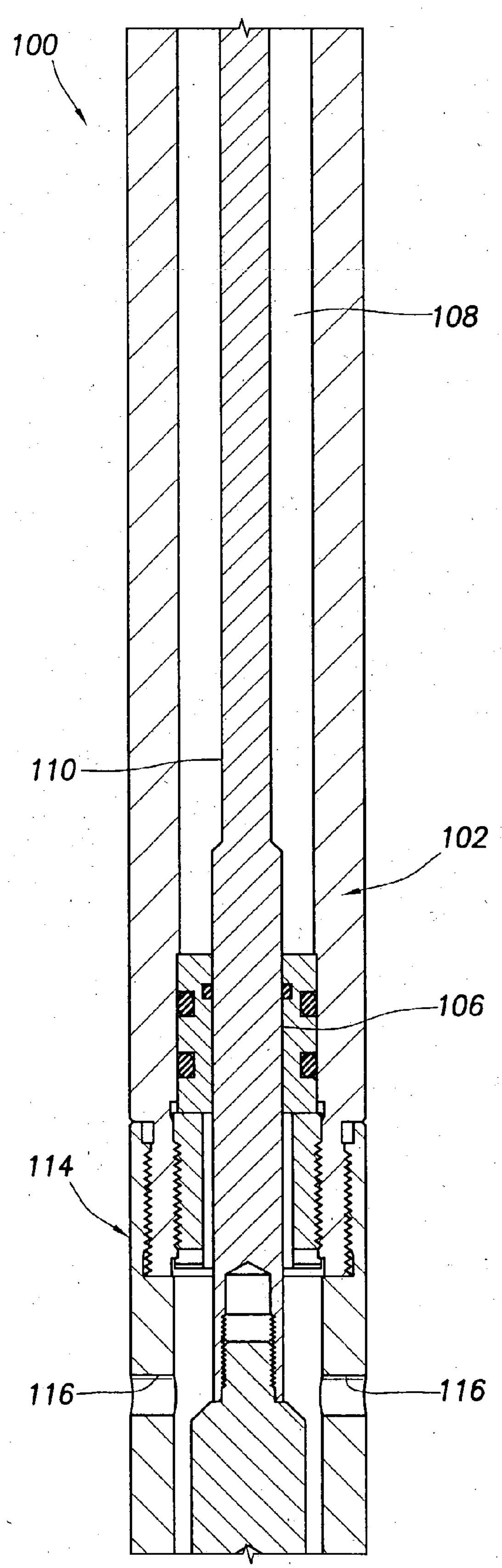

100
108
110
102
106
114
116
116

FIG. 4C

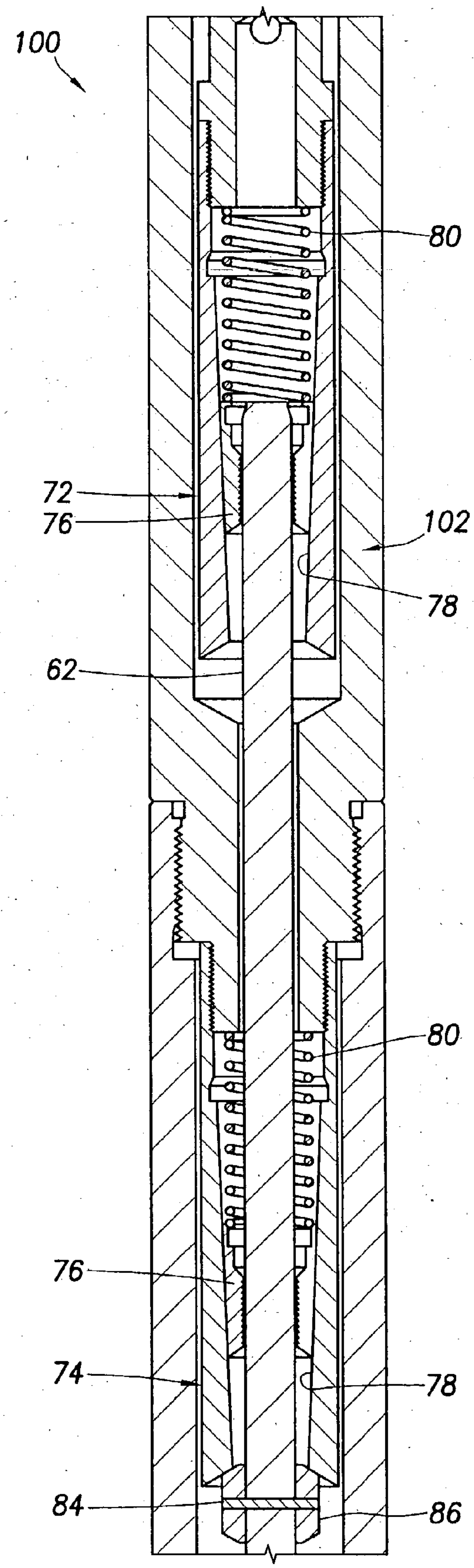

100
80
72
76
102
78
62
80
76
74
78
84
86

FIG. 4D

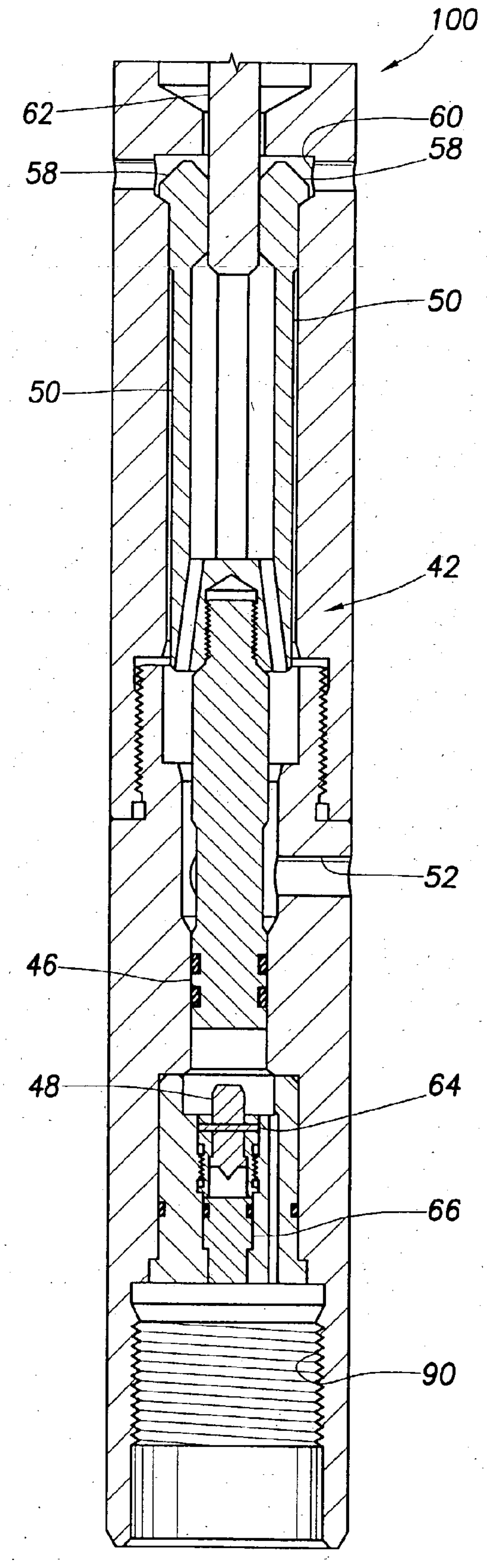

100
62
60
58
58
50
50
42
52
46
48
64
66
90

FIG.4E

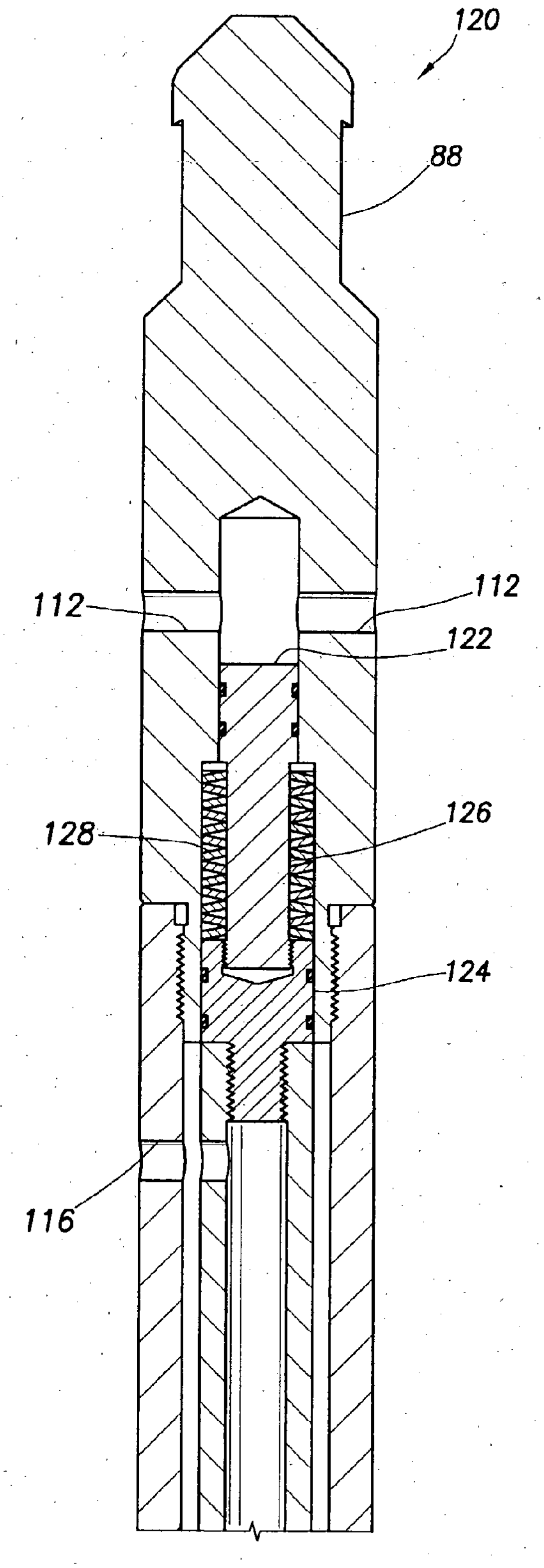

120
88
112
112
122
128
126
124
116

FIG.5A

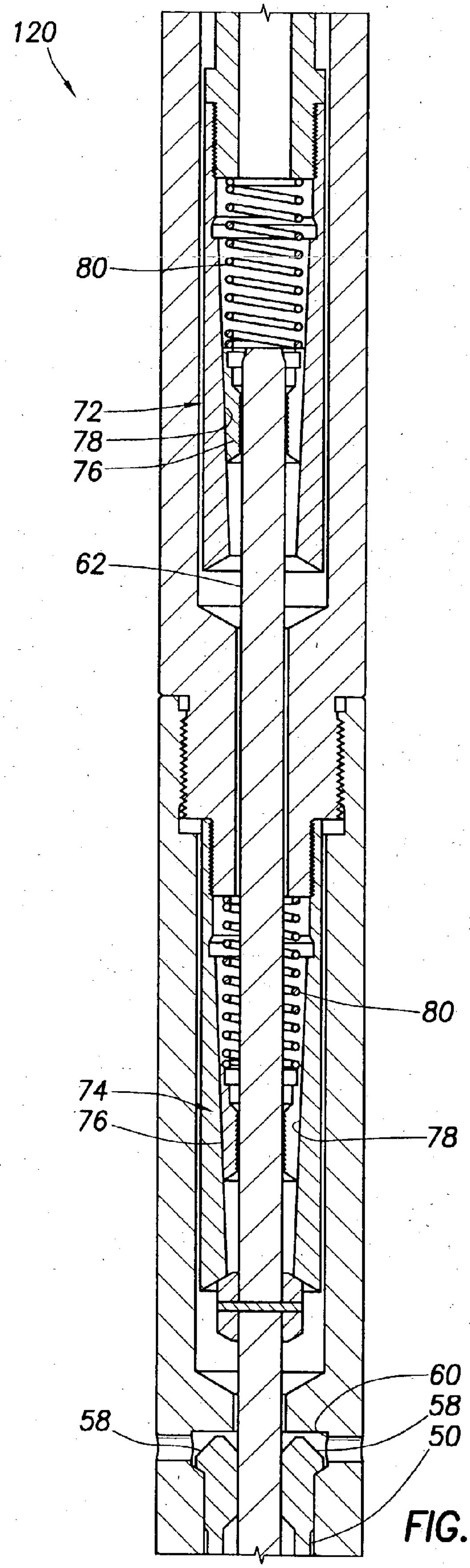


FIG.5B

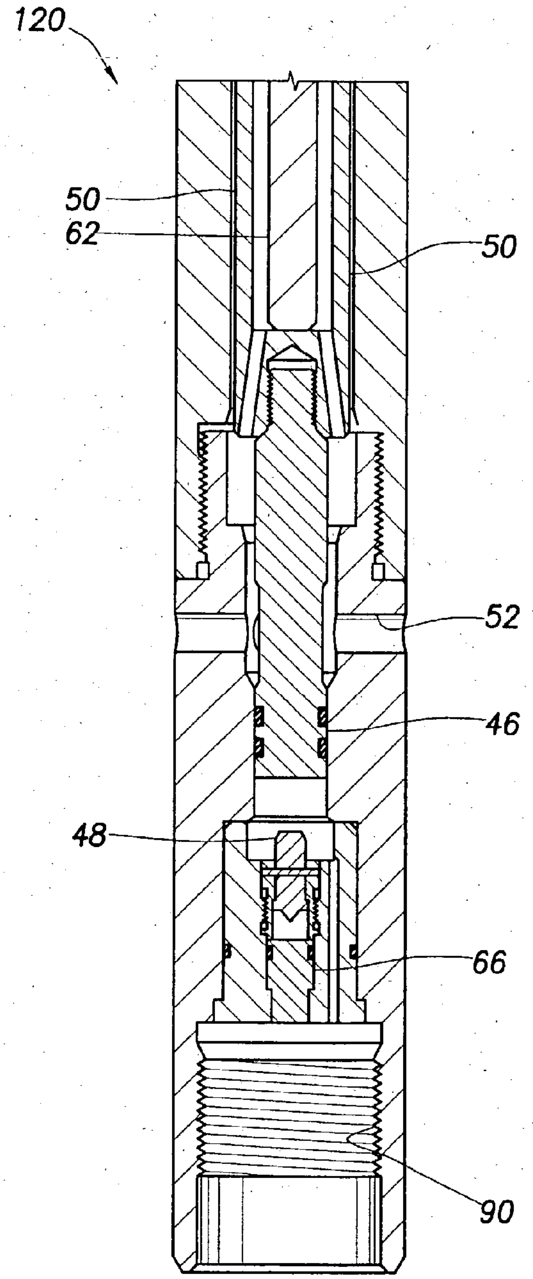


FIG.5C

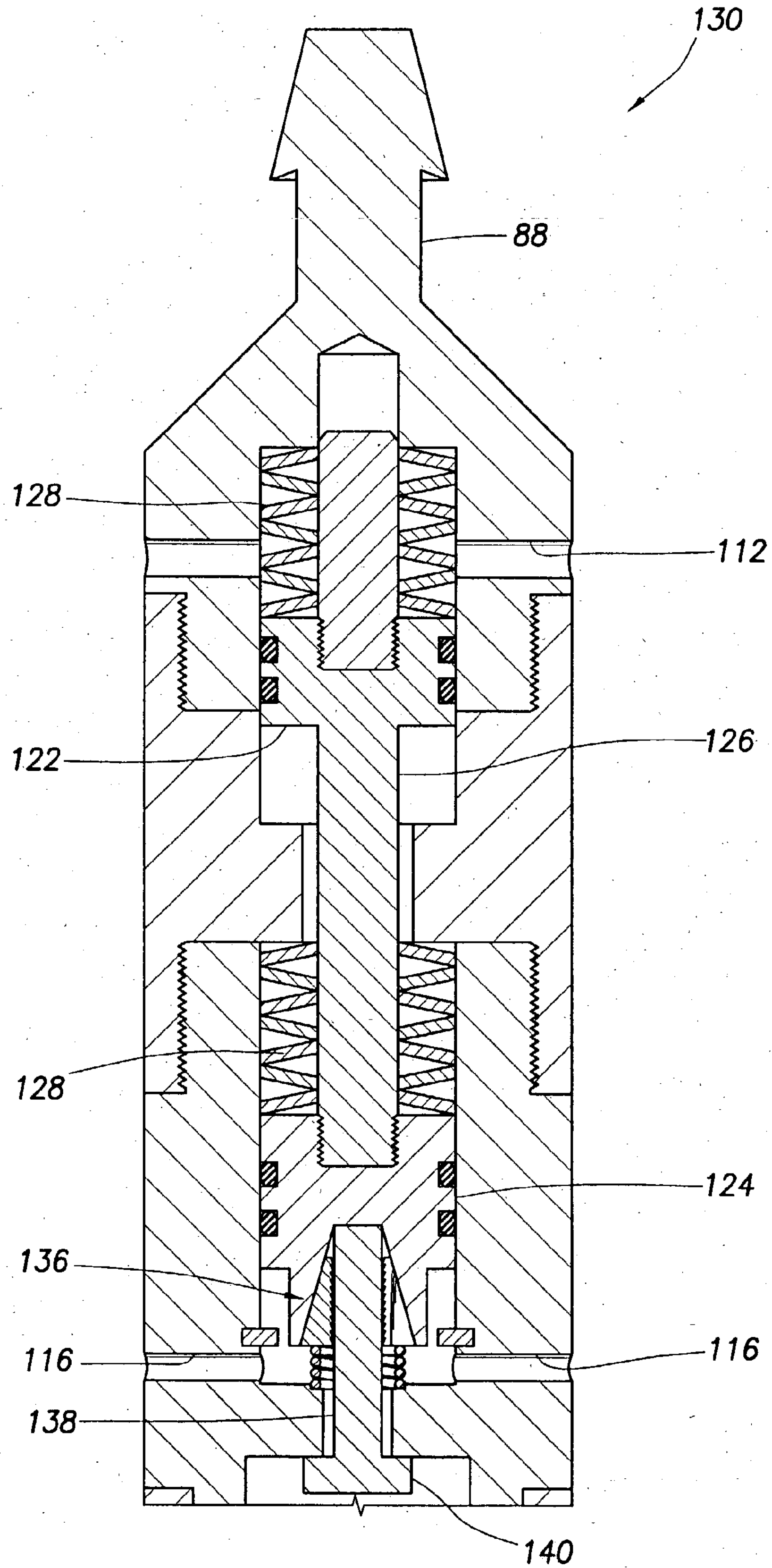


FIG. 6A

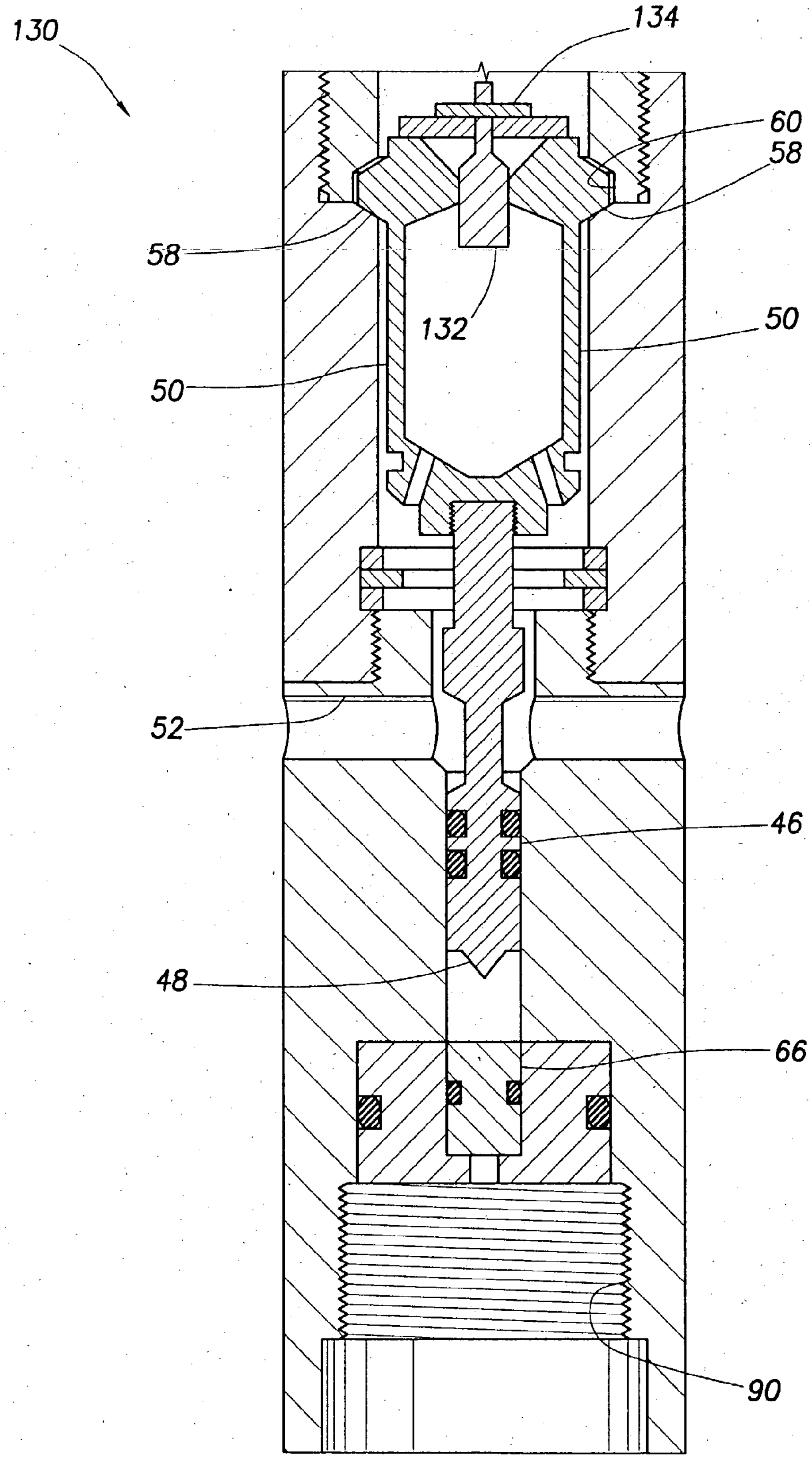


FIG. 6B

RETRIEVABLE MULTI-PRESSURE CYCLE FIRING HEAD

BACKGROUND

[0001] The present invention relates generally to operations performed and equipment utilized in conjunction with subterranean wells and, in an embodiment described below, more particularly relates to a multi-pressure cycle firing head for perforating guns.

[0002] Pressure actuated firing heads are used frequently to initiate detonation of shaped charges in perforating guns. Typically, a pressure operated firing head is set up to actuate at a particular predetermined pressure level in a well. When the pressure level is reached, the firing head is actuated and initiates detonation of the perforating gun shaped charges, either immediately or after a time delay.

[0003] However, in some situations it is not desirable for a pressure actuated firing head to operate in this manner. For example, it may be necessary to pressure test a packer or other equipment prior to detonating the perforating guns. It may not be feasible to exceed the pressure level used in the pressure test at the time it is desired to detonate the perforating guns.

[0004] As another example, the firing head may experience multiple pressure increases in the well prior to the time at which it is desired to actuate the firing head. This situation could occur due to a swabbing effect when the guns and firing head are conveyed into the well, when the guns are positioned in the well while other operations are being performed, etc.

[0005] Therefore, it may be seen that it would be beneficial to provide a pressure actuated firing head which can experience multiple pressure applications prior to firing. In addition, or alternatively, other benefits, such as simplicity of design, elimination of pressurized gas chambers, economy of manufacture, convenience of operation, etc., could be provided in a pressure actuated firing head.

SUMMARY

[0006] In carrying out the principles of the present invention, in accordance with an embodiment thereof, a multi-cycle pressure actuated firing head is provided.

[0007] In one aspect of the invention, a method of firing a firing head to detonate a perforating gun in a subterranean well is provided. The method includes the steps of: conveying the firing head into the well; then alternately increasing and decreasing a pressure level in the well proximate the firing head multiple times; and firing the firing head in response to performance of a predetermined number of the pressure level alternating steps.

[0008] In another aspect of the invention, a pressure actuated firing head for detonating a perforating gun in a subterranean well is provided. The firing head includes a firing mechanism and a member which displaces incrementally in response to alternating pressure increases and decreases applied to the firing head. The firing mechanism fires when the member displaces a predetermined distance.

[0009] In a further aspect of the invention, another pressure actuated firing head for detonating a perforating gun in a subterranean well is provided. The firing head includes a firing mechanism and a displacement mechanism which displaces a member of the firing head in response to a decrease in a pressure level proximate the firing head in the well. The firing mechanism fires when the member is displaced by the displacement mechanism.

[0010] These and other features, advantages, benefits and objects of the present invention will become apparent to one of ordinary skill in the art upon careful consideration of the detailed description of representative embodiments of the invention hereinbelow and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] **FIG. 1** is a schematic cross-sectional view of a first method embodying principles of the present invention;

[0012] **FIG. 2** is a schematic cross-sectional view of a second method embodying principles of the present invention;

[0013] FIGS. **3**A-D are cross-sectional views of successive axial portions of a first apparatus embodying principles of the present invention;

[0014] FIGS. **4**A-E are cross-sectional views of successive axial portions of a second apparatus embodying principles of the present invention;

[0015] FIGS. **5**A-C are schematic cross-sectional views of successive axial portions of a third apparatus embodying principles of the present invention; and

[0016] **FIGS. 6A & B** are cross-sectional views of successive axial portions of a fourth apparatus embodying principles of the present invention

DETAILED DESCRIPTION

[0017] Representatively illustrated in **FIG. 1** is a method **10** which embodies principles of the present invention. In the following description of the method **10** and other apparatus and methods described herein, directional terms, such as "above", "below", "upper", "lower", etc., are used only for convenience in referring to the accompanying drawings. Additionally, it is to be understood that the various embodiments of the present invention described herein may be utilized in various orientations, such as inclined, inverted, horizontal, vertical, etc., and in various configurations, without departing from the principles of the present invention.

[0018] In the method **10**, a tubular string **12** is conveyed into a wellbore **14**. The tubular string **12** includes a packer **16**, a valve **18**, a firing head **20** and a perforating gun **22**. The firing head **20** is used to detonate shaped charges (not visible in **FIG. 1**) in the perforating gun **22**, in order to form perforations **24** extending outwardly from the wellbore **14**.

[0019] It should be clearly understood that the method **10**, and other methods and apparatus described herein, are used merely as examples of applications of the principles of the invention, in order that a person skilled in the art will fully understand how to make and use the invention. However, the principles of the invention are not limited to the specific details of the methods and apparatus described herein. For example, the tubular string **12** in the method **10** could include more, less or different elements instead of those depicted in **FIG. 1**, these elements could be conveyed together or separately into the wellbore **14**, the elements could be differently configured or arranged relative to each other, or relative to the wellbore **14**, etc.

[**0020**] While the firing head **20** and the perforating gun **22** are in the wellbore **14**, the firing head may be subjected to a number of increases and decreases in the pressure level proximate the firing head. For example, increases and decreases in the pressure level may be due to circulating fluids through the valve **18**, setting the packer **16**, pressure testing the packer, etc. However, the firing head **20** is a pressure actuated firing head, i.e., the firing head responds to pressure in the wellbore **14** to fire the gun **22**. It would be very hazardous and/or costly for the firing head **20** to fire at any time other than the appropriate time.

[**0021**] One of the problems solved by the present invention is how to prevent the firing head **20** from firing the gun **22** prematurely. Another of the problems solved by the present invention is how to actuate the firing head **20** at the appropriate time. Yet another problem solved by the present invention is how to permit the firing head **20** to be retrieved from the wellbore **14** without firing the gun **22**.

[**0022**] These problems are solved by providing firing heads (several embodiments of which are described below) which respond to the pressure level in the wellbore **14** in unique ways. One firing head responds to alternating increases and decreases in the pressure level. The firing head fires only when a predetermined number of pressure increases and decreases are performed. The firing head can be safely retrieved from a well if the predetermined number of pressure increases and decreases has not yet been performed.

[**0023**] Another firing head responds to a decrease in the pressure level only after a predetermined increase in the pressure level has been experienced. The firing head can be safely retrieved from the well if the predetermined increase in the pressure level has not been experienced. If the predetermined increase in the pressure level has been experienced, or if it is not known whether the predetermined increase in the pressure level has been experienced, the firing head can be safely retrieved from the well by separating it from the perforating gun prior to retrieving the firing head.

[**0024**] Referring additionally now to **FIG. 2**, another method **30** embodying principles of the invention is representatively illustrated. Elements of the method **30** which are similar to those previously described are indicated in **FIG. 2** using the same reference numbers. The method **30** demonstrates additional circumstances in which the benefits of the invention may be achieved.

[**0025**] In the method **30**, the firing head **20** and perforating gun **22** are conveyed into the wellbore **14** separate from a tubular string **32** which includes the packer **16** and valve **18**. For example, the firing head **20** and perforating gun **22** could be conveyed using a wireline, coiled tubing string, a production tubing string, etc. The firing head **20** and gun **22** are anchored in the wellbore **14** using a gun hanger **34** set in the wellbore **14**.

[**0026**] Alternatively, the firing head **20** could be conveyed into the wellbore **14** separate from the gun **22**. In this manner, the gun **22** could be positioned in the wellbore **14** prior to conveying the firing head **20** into the wellbore and connecting the firing head to the gun, so that pressure increases and decreases in the well prior to conveying the firing head therein would not actuate the firing head. For example, the gun **22** could be positioned in the well during pressure tests of casing or liner **36** lining the wellbore **14**, without the risk of firing the firing head **20**.

[**0027**] A connection between the firing head **20** and the gun **22** may be provided by a conventional detonation transfer connection **38** of the type known to those skilled in the art. The connection **38** is a releasable connection which transfers detonation from the firing head **20** to the gun **22**. Thus, the firing head **20** may be connected to the gun **22** after the gun has been positioned in the wellbore **14**, and the firing head may be separated from the gun after their connection to each other, whether or not the firing head and gun were connected to each other when they were initially conveyed into the wellbore.

[**0028**] Referring additionally to FIGS. **3**A-D, a pressure actuated firing head **40** embodying principles of the invention is representatively illustrated. The firing head **40** may be used for the firing head **20** in the methods **10**, **30** described above. The firing head **40** may also be used in other methods, without departing from the principles of the invention.

[**0029**] The firing head **40** includes a firing mechanism **42** and a displacement mechanism **44**. The firing mechanism **42** includes a firing piston **46**, a firing pin **48** and a release mechanism **28** including a series of circumferentially distributed release members or collets **50** attached to the piston. Note that release members other than the collets **50** could be used, for example, a C-ring or snap ring, keys, dogs, etc., could be used in place of the collets.

[**0030**] Wellbore pressure is applied to an upper portion of the piston **46** via one or more openings **52** formed through an outer housing assembly **54** of the firing head **40**. A lower portion of the piston **46** is exposed to pressure in an atmospheric chamber **56**. Thus, when the firing head **40** is subjected to pressure in a wellbore greater than atmospheric pressure, the piston **46** is biased downwardly by the wellbore pressure.

[**0031**] The collets **50** initially prevent downward displacement of the piston **46**. Upper radially enlarged ends **58** of the collets **50** are received in an annular recess **60** formed in the housing assembly **54**. A member or rod **62** outwardly supports the collets **50**, so that the upper ends **58** remain engaged with the recess **60**, thereby preventing downward displacement of the piston **46**.

[**0032**] Note that, if the rod **62** is displaced upward a sufficient distance relative to the collets **50**, the rod will eventually fail to outwardly support the collets. This will permit the upper ends **58** of the collets **50** to disengage from the recess **6**o, thereby permitting the piston **46** to displace downwardly and impact the firing pin **48**. This impact will shear a pin **64** retaining the firing pin **48** in position and the impact will be transmitted to a detonation initiator **66**. If the firing head **40** is operatively connected to a perforating gun when the initiator **66** is impacted, the gun will be detonated in a manner known to those skilled in the art.

[**0033**] Therefore, it will be readily appreciated that upward displacement of the rod **62** is used to fire the firing head **40**. This displacement of the rod **62** is controlled by the displacement mechanism **44**. However, it will also be appreciated that displacement of the rod **62** will not result in firing of the firing head **40**, unless the firing head is subjected to wellbore pressure greater than atmospheric pressure to downwardly bias the piston **46** and, thus, the firing head is inherently prevented from firing at the surface.

[**0034**] The displacement mechanism **44** includes a piston **68**, a biasing device **70** and two engagement devices **72**, **74**. As depicted in the drawings, the biasing device **70** is a pressurized gas chamber containing, for example, nitrogen at an elevated pressure. Other biasing devices, such as springs, etc., could be used in place of the chamber **70**, without departing from the principles of the invention.

[**0035**] The engagement devices **72**, **74** are depicted in the drawings as including gripping members or segmented slips **76** received in tapered bores **78**, the slips being biased toward reduced diameter portions of the bores by springs **80**. The rod **62** is received within the slips **76**, each of which operates to prevent downward displacement of the rod, but to permit upward displacement of the rod relative thereto. Thus, each of the engagement devices **72**, **74** permits only upward displacement of the rod **62**. It should be clearly understood that other types of engagement devices could be used in the firing head **40**, in keeping with the principles of the invention.

[**0036**] The upper engagement device **72** is connected to the piston **68** and displaces therewith. The other engagement device **74** is attached to the housing assembly **54**. If the piston **68** displaces upward, the upper engagement device **72** will cause the rod **62** to be displaced upward with the piston (the lower engagement device **74** permitting such upward displacement of the rod). If the piston **68** displaces downward, the lower engagement device **74** will prevent the rod **62** from displacing downward with the piston (the upper engagement device **72** permitting upward displacement of the rod relative to the piston).

[**0037**] Therefore, it will be readily appreciated that, by reciprocating the piston **68** alternately upward and downward relative to the housing assembly **54**, the rod **62** can be made to displace incrementally upward with every upward displacement of the piston. When the rod **62** has been displaced incrementally upward a sufficient number of times, the rod will displace a corresponding sufficient distance so that it no longer outwardly supports the collets **50**, as described above.

[**0038**] An upper portion of the piston **68** is exposed to pressure in the gas chamber **70**. A lower portion of the piston **68** is exposed to wellbore pressure via one or more openings **82** formed through the housing assembly **54**. When wellbore pressure exceeds pressure in the gas chamber **70**, the piston **68** will displace upwardly. The piston **68** has been upwardly displaced as viewed in **FIG. 3B**.

[**0039**] When pressure in the gas chamber **70** exceeds wellbore pressure, the piston **68** will displace downwardly. Thus, to reciprocate the piston **68** upwardly and downwardly, pressure in the wellbore proximate the firing head **40** should be alternately increased and decreased, respectively above and below the pressure in the gas chamber **70**.

[**0040**] Preferably, although not necessarily, the pressure in the gas chamber **70** is set so that it is greater than the wellbore pressure at any time up until it is desired to fire the firing head **40**. For example, if prior to the time it is desired to fire the firing head **40** wellbore pressure is expected to be as great as 10,000 psi proximate the firing head, the gas chamber pressure may be set at 11,000 or 12,000 psi. In this manner, upward displacement of the piston **68** may be prevented until it is desired to fire the firing head **40**, at which time the wellbore pressure may be alternately increased above the gas chamber pressure and decreased below the gas chamber pressure.

[**0041**] In some situations it may not be feasible to set the gas chamber pressure greater than the maximum wellbore pressure up until it is desired to fire the firing head **40**. For example, if the maximum wellbore pressure is due to a packer pressure test, it may not be desirable to subsequently exceed that pressure in the wellbore at the firing head **40**. In these situations, the gas chamber **70** pressure may be set less than the maximum wellbore pressure.

[**0042**] A shear pin **84** may be used to prevent upward displacement of the rod **62** until a predetermined wellbore pressure is reached. The shear pin **84** passes through the rod **62** and an annular collar **86** encircling the rod and abutting a lower end of the lower engagement device **74**. When the predetermined wellbore pressure is reached, the pin **84** shears, thereby permitting upward displacement of the rod **62**.

[**0043**] The shear pin **84** may be installed in any of several axially spaced apart holes **92** provided in the rod **62**. By installing the pin **84** in a more upwardly positioned one of the holes **92**, the rod **62** is more downwardly positioned initially relative to the housing assembly **54**, and so it takes a greater number of pressure cycles to upwardly displace the rod a sufficient distance to fire the firing head **40**. Similarly, by installing the pin **84** in a more downwardly positioned one of the holes **92**, the rod **62** is more upwardly positioned initially relative to the housing assembly **54**, and so it takes a lesser number of pressure cycles to upwardly displace the rod a sufficient distance to fire the firing head **40**. The rod **62** can also be made longer or shorter, or initially positioned more upwardly or downwardly in the firing head **40** by other means, to achieve a desired number of pressure cycles required to fire the firing head.

[**0044**] The shear pin **84** may be set to shear at a wellbore pressure exceeding the gas chamber **70** pressure by a certain amount, for example, 1,000 psi. In this manner, reciprocating displacement of the piston **68** while the firing head **40** is conveyed into the well, or when other pressure increases and decreases are experienced, may be prevented in those situations where the gas chamber **70** pressure is set lower than the maximum wellbore pressure to be experienced at the firing head **40** prior to the time it is desired to fire the firing head.

[**0045**] For example, if the gas chamber **70** pressure is set below a packer test pressure, the shear pin **84** could be set to shear at a wellbore pressure greater than the gas chamber pressure but less than the packer test pressure. The first upward displacement of the piston **68** would occur when the shear pin **84** shears (for example, when the packer is tested). Subsequent decreases and increases in wellbore pressure, respectively below and above the gas chamber **70** pressure will cause the piston **68** to reciprocate downwardly and upwardly in the firing head **40**, eventually displacing the rod **62** a sufficient distance to fire the firing head.

[**0046**] Of course, it is not necessary for the shear pin **84** to be set to shear at a wellbore pressure related to any particular event, such as a packer pressure test. For example, the shear pin **84** could be set to shear at a wellbore pressure corresponding to an elevated hydrostatic pressure to be experienced by the firing head **40** during or after conveyance into the well, in order to prevent reciprocating displacement of the piston **68** prior to the firing head experiencing that elevated hydrostatic pressure.

[**0047**] It should also be noted that, until the shear pin **84** shears, the firing head **40** may be safely retrieved from the well without firing. In addition, until a wellbore pressure greater than the gas chamber **70** pressure has been experienced at the firing head **40**, the firing head may also be retrieved safely from the well. Furthermore, until a sufficient number of alternating wellbore pressure increases and decreases have been experienced at the firing head **40**, the firing head may be safely retrieved from the well. And, since the firing mechanism **42** actually fires only in response to a pressure increase (resulting in upward displacement of the rod **62**), the firing head **40** may be safely retrieved from the well as long as a pressure increase is not experienced by the firing head during such retrieval.

[**0048**] A conventional fishing neck **88** is provided at an upper end of the firing head **40** as depicted in the drawings, for conveyance of the firing head into the well (as in the method **30**) or retrieval of the firing head from the well, either connected to, or separate from, a perforating gun. Alternatively, the firing head **40** may be provided with a connection permitting it to be interconnected in a tubing string (as in the method **10**).

[**0049**] A conventional threaded seal bore connection **90** is provided at a lower end of the firing head **40** as depicted in the drawings, for connection of the firing head to a perforating gun, or to a detonation transfer connection. However, it should be understood that any types of connections may be provided on the firing head **40**, the firing head may be connected above or below a perforating gun, and the firing head may be conveyed into the well, or retrieved therefrom, by any method, in keeping with the principles of the invention. These considerations apply equally well to the other firing heads described below.

[**0050**] Referring additionally now to FIGS. **4**A-E, another firing head **100** embodying principles of the invention is representatively illustrated. The firing head **100** may be used for the firing head **20** in the methods **10** and **30**, or in any other methods. The firing head **100** is similar in many respects to the firing head **40** described above, and elements shown in FIGS. **4**A-E which are similar to those previously described are indicated using the same reference numbers. Note that the firing mechanism **42** of the firing head **100** is substantially identical to that of the firing head **40** (the firing mechanism firing the firing head by upwardly displacing the rod **62**).

[**0051**] However the firing head **100** has a different displacement mechanism **102** for displacing the rod **62**. The displacement mechanism **102** includes upper and lower pistons **104**, **106**, with a biasing device or pressurized gas chamber **108** between the pistons. An elongated rod-like member **110** connects the pistons **104**, **106** to each other, so that they displace with each other. This assembly (pistons **104**, **106** and rod member **110**) is connected to the upper engagement device **72**, so that the rod **62** displaces upwardly with the assembly.

[**0052**] An upper portion of the upper piston **104** is exposed to wellbore pressure via one or more openings **112** formed through a housing assembly **114**. A lower portion of the lower piston **106** is exposed to wellbore pressure via one or more openings **116** formed through the housing assembly **114**. Because the upper piston **104** has a greater piston area than the lower piston **106**, wellbore pressure will bias the combined pistons and rod member **10** assembly downwardly.

[**0053**] Pressure in the chamber **108** is exposed to a lower portion of the upper piston **104**, and to an upper portion of the lower piston **106**. Since the upper piston **104** has a greater piston area than the lower piston **106**, pressure in the chamber **108** will bias the combined pistons and rod member **110** assembly upwardly. By alternately increasing and decreasing the wellbore pressure, respectively above and below the gas chamber **108** pressure, the rod **62** may be incrementally displaced upwardly a sufficient distance to fire the firing head **100**, similar to the manner in which the firing head **40** may be operated as described above.

[**0054**] However, the combined pistons **104**, **106** and rod member **110** assembly displace upwardly in response to a decrease in the wellbore pressure, instead of in response to an increase in wellbore pressure. Thus, the gas chamber **108** may pressurized so that it is at a pressure greater than wellbore pressure experienced at the firing head **100** while it is being conveyed into the well. In this manner, when it is desired to fire the firing head, wellbore pressure at the firing head **100** may be increased above the gas chamber **108** pressure to downwardly displace the pistons **104**, **106**, rod member **110** and upper engagement device **72**, and then wellbore pressure at the firing head may be decreased to upwardly displace those elements along with the rod **62**.

[**0055**] The shear pin **84** may be set so that a certain decreased wellbore pressure at the firing head **100** is required to upwardly displace the rod **62**, as in the firing head **40** described above. In addition, the lower end of the rod **62** may be positioned within the collets **50** a distance which corresponds to only a single upward displacement of the rod **62**. In this manner, the firing head **100** may be fired upon the first decrease in wellbore pressure at the firing head **100** after the wellbore pressure exceeds the pressure in the gas chamber **108**. This decrease in wellbore pressure at the firing head **100** may be achieved, for example, by using gas lift equipment to displace fluid out of the wellbore.

[**0056**] Referring additionally now to FIGS. **5**A-C, another firing head **120** embodying principles of the invention is representatively and schematically illustrated. The firing head **120** may be used for the firing head **20** in the methods **10** and **30**, or in any other methods. The firing head **120** is similar in many respects to the firing head too described above, and elements which are similar to those previously described are indicated in FIGS. **5**A-C using the same reference numbers.

[**0057**] The firing head **120** is distinguished from the firing head **100** by two main differences. First, an upper piston **122** of the firing head **120** has a smaller piston area than a lower piston **124**. Thus, wellbore pressure at the firing head **120** biases the pistons **122**, **124** and a rod member **126** connecting the pistons upwardly, instead of downwardly as in the firing head **100**. Accordingly, the firing head **120** fires upon an increase in wellbore pressure at the firing head, **20** similar to the firing head **40**.

[0058] Second, a biasing device **128** of the firing head **120** biases the pistons **122**, **124** and rod member **110** downwardly, instead of upwardly as in the firing head **100**. The biasing device **128** is one or more springs, such as Bellville washers, of the type known to those skilled in the art.

[0059] Since the rod **62** may be displaced incrementally upward by alternately increasing and decreasing the wellbore pressure at the firing head **120**, so that the biasing force exerted by the wellbore pressure on the pistons **122**, **124** is respectively greater than and less than the biasing force exerted by the springs **128**, the firing head **120** may be operated in the same manners as those described above for the firing head **40**. For example, the springs **128** may be configured so that they exert a biasing force greater than that exerted by the wellbore pressure on the pistons **122**, **124** at any time up until it is desired to fire the firing head **120**. When it is desired to fire the firing head **120**, the wellbore pressure may be alternately increased and decreased to incrementally displace the rod **62** upward.

[0060] As another example, the springs **128** may be configured so that they exert a biasing force less than that exerted by the maximum wellbore pressure on the pistons **122**, **124** prior to the time it is desired to fire the firing head **120**, but greater than that exerted by the wellbore pressure on the pistons during conveyance of the firing head into the well. This will prevent the pistons **122**, **124** from reciprocating upward and downward during conveyance into the well, while not requiring the wellbore pressure to be increased greater than the maximum wellbore pressure on the pistons **122**, **124**, when it is desired to fire the firing head **120**.

[0061] Referring additionally now to **FIGS. 6A & B**, another firing head **130** embodying principles of the invention is representatively and schematically illustrated. The firing head **130** may be used for the firing head **20** in the methods **10**, **30**, or in other methods. The firing head is similar in many respects to the firing head **120** described above, and elements which are similar to those previously described are indicated in **FIGS. 6A & B** using the same reference numbers.

[0062] One significant difference between the firing heads **120**, **130** is that multiple biasing devices **128** are used in the firing head **130**. An upper one of the biasing devices **128** exerts a downwardly directed force on the upper piston **122**. A lower one of the biasing devices **128** exerts a downwardly directed biasing force on the lower piston **124**.

[0063] Another significant difference is that the firing head **130** includes a member **132** outwardly supporting the collets **50** which is downwardly, instead of upwardly, displaced in order to fire the firing head. The member **132** is initially positioned in the upper ends **58** of the collets and secured with a shear pin **134**. When a sufficiently great downwardly directed force is applied to an upper end of the member **132**, the pin **134** shears, permitting the member to displace downwardly. This downward displacement of the member **132** causes the upper ends **58** of the collets **50** to disengage from the recess **60**, permitting the collets and piston **46** to displace downwardly and fire the firing head **130**.

[0064] A further difference is that the lower piston **124** has an engagement device **136** attached thereto which is oppositely configured as compared to the engagement devices **72**, **74** described above. That is, the engagement device **136** permits downward displacement of a rod member **138** therethrough, but prevents upward displacement of the rod member.

[0065] Thus, when the pistons **122**, **124** displace upwardly, the rod member **138** extends outwardly and downwardly from the lower piston **124**, rather than displacing upwardly with the lower piston. Conversely, when the pistons **122**, **124** displace downwardly, the rod member **138** displaces downwardly with the lower piston **124**, the engagement device **136** preventing upward displacement of the rod member relative to the lower piston.

[0066] Actuation of the firing head **130** is as follows: When wellbore pressure at the firing head **130** exerts an upwardly biasing force on the pistons **122**, **124** greater than a downwardly biasing force exerted by the biasing devices **128**, the pistons and rod member **126** displace upwardly. A radially enlarged lower end **140** of the rod member **138** prevents it from displacing upwardly with the lower piston **124**, and the engagement device **136** permits the lower piston to displace upwardly relative to the rod member. Thus, the rod member **138** extends further outwardly and downwardly from the lower piston **124** as it displaces upwardly.

[0067] When wellbore pressure at the firing head **130** is subsequently decreased, the downwardly biasing force exerted by the biasing devices **128** eventually exceeds the upwardly biasing force exerted on the pistons **122**, **124** by the wellbore pressure, and the pistons displace downwardly. The engagement device **136** prevents downward displacement of the lower piston **124** relative to the rod member **138**, and so the rod member displaces downwardly with the lower piston.

[0068] As the rod member **138** displaces downwardly, the lower end **140** of the rod member contacts an upper end of the member **132** and applies the downwardly directed biasing force to the member. When the downwardly directed biasing force is sufficiently great, the pin **134** shears, permitting the member **132** to displace downwardly. Downward displacement of the member **132** causes the upper ends **58** of the collets **50** to disengage from the recess **60**, thereby firing the firing head **130** as described above. Note that the shear pin **134** may be sized so that a certain predetermined decreased wellbore pressure must be reached before the pin will shear to release the member **132**.

[0069] Of course, a person skilled in the art would, upon a careful consideration of the above description of representative embodiments of the invention, readily appreciate that many modifications, additions, substitutions, deletions, and other changes may be made to these specific embodiments, and such changes are contemplated by the principles of the present invention. Accordingly, the foregoing detailed description is to be clearly understood as being given by way of illustration and example only, the spirit and scope of the present invention being limited solely by the appended claims and their equivalents.

What is claimed is:

1. A method of firing a firing head to detonate a perforating gun in a subterranean well, the method comprising the steps of:

conveying the firing head into the well;

then alternately increasing and decreasing a pressure level in the well proximate the firing head multiple times; and

firing the firing head in response to performance of a predetermined number of the pressure level alternating steps.

2. The method according to claim 1, wherein the pressure level alternating step further comprises increasing the pressure level above a predetermined pressure multiple times, and wherein the firing step further comprises firing the firing head in response to performance of a predetermined number of the pressure level increasing steps.

3. The method according to claim 1, wherein the pressure level alternating step further comprises decreasing the pressure level below a predetermined pressure after increasing the pressure level, and wherein the firing step further comprises firing the firing head in response to performance of the pressure level decreasing step.

4. The method according to claim 1, wherein the conveying step further comprises conveying the firing head into the well attached to the perforating gun.

5. The method according to claim 4, wherein the pressure level alternating steps are performed while the firing head is attached to the perforating gun in the well.

6. The method according to claim 1, wherein the conveying step further comprises conveying the firing head into the well separate from the perforating gun.

7. The method according to claim 1, further comprising the step of operatively attaching the firing head to the perforating gun after the conveying step and prior to the firing step.

8. The method according to claim 1, further comprising the step of incrementally displacing a member of the firing head in response to each of the pressure level alternating steps.

9. The method according to claim 8, wherein the firing step further comprises firing the firing head when the member has displaced a predetermined total distance.

10. The method according to claim 8, further comprising the step of releasing a firing pin of the firing head to displace in response to a biasing force exerted by the pressure level, when the member has displaced a predetermined total distance.

11. The method according to claim 8, wherein the incrementally displacing step further comprises incrementally displacing the member in response to a selected one of the steps of increasing and decreasing the pressure level, and retaining the member against displacement in response to the other one of the steps of increasing and decreasing the pressure level.

12. The method according to claim 1, further comprising the step of displacing a piston of the firing head in alternating opposite directions against a force exerted by a biasing device, the displacing step being performed in response to the pressure level alternating step.

13. A pressure actuated firing head for detonating a perforating gun in a subterranean well, the firing head comprising:

a firing mechanism; and

a member which displaces incrementally in response to alternating pressure increases and decreases applied to the firing head, the firing mechanism firing when the member displaces a predetermined distance.

14. The firing head according to claim 13, wherein the member displaces in response to each of the pressure increases.

15. The firing head according to claim 13, wherein the member remains motionless during each of the pressure decreases.

16. The firing head according to claim 13, further comprising a displacement mechanism operative to incrementally displace the member in response to the pressure increases and decreases, the displacement mechanism including a piston and a biasing device.

17. The firing head according to claim 16, wherein during the pressure increases the piston displaces in a first direction against a force exerted by the biasing device, and wherein during the pressure decreases the biasing device displaces the piston in a second direction opposite to the first direction.

18. The firing head according to claim 16, wherein the displacement mechanism further includes a first engagement device which engages the member, so that the member displaces with the piston when the piston displaces in a first direction, and a second engagement device which engages the member, so that the piston displaces relative to the member when the piston displaces in a second direction opposite to the first direction.

19. The firing head according to claim 18, wherein each of the first and second engagement devices includes at least one grip member which grips the member and prevents displacement of the member in the second direction.

20. The firing head according to claim 18, wherein the first engagement device is attached to, and displaces with, the piston, and wherein the piston displaces reciprocably relative to the second engagement device in response to the pressure increases and decreases.

21. The firing head according to claim 16, wherein the biasing device is at least one spring.

22. The firing head according to claim 16, wherein the biasing device is at least one chamber having pressurized gas therein.

23. The firing head according to claim 13, wherein the firing mechanism includes a release mechanism and a firing pin, the release mechanism permitting the firing pin to displace when the member has displaced the predetermined distance.

24. The firing head according to claim 23, wherein the release mechanism includes at least one collet supported initially by the member, the collet becoming unsupported and thereby permitting the firing pin to displace when the member has displaced the predetermined distance.

25. The firing head according to claim 23, wherein the firing pin displaces in response to pressure proximate the firing head when the member has displaced the predetermined distance.

26. A pressure actuated firing head for detonating a perforating gun in a subterranean well, the firing head comprising:

a firing mechanism; and

a displacement mechanism which displaces a member of the firing head in response to a decrease in a pressure level proximate the firing head in the well, the firing mechanism firing when the member is displaced by the displacement mechanism.

27. The firing head according to claim 26, wherein the displacement mechanism displaces the member in response to only a single decrease in the pressure level in the well.

28. The firing head according to claim 26, wherein the displacement mechanism displaces the member in response to the decrease in the pressure level only if the decrease in the pressure level is preceded by an increase in the pressure level.

29. The firing head according to claim 28, wherein the displacement mechanism displaces the member in response to the decrease in the pressure level only if the decrease in the pressure level is preceded by the increase in the pressure level above a first predetermined pressure.

30. The firing head according to claim 29, wherein the displacement mechanism displaces the member in response to the decrease in the pressure level only if the decrease in the pressure level decreases the pressure level below a second predetermined pressure.

31. The firing head according to claim 26, wherein the member displaces only in response to the decrease in the pressure level.

32. The firing head according to claim 26, wherein the member remains motionless during pressure increases in the well.

33. The firing head according to claim 26, wherein the displacement mechanism includes a piston and a biasing device.

34. The firing head according to claim 33, wherein during increases in the pressure level, the piston displaces in a first direction against a force exerted by the biasing device, and wherein during the decrease in the pressure level, the biasing device displaces the piston in a second direction opposite to the first direction.

35. The firing head according to claim 33, wherein the displacement mechanism further includes an engagement device which permits the member to displace relative to the piston when the piston displaces in a first direction, and which engages the member so that the member displaces with the piston when the piston displaces in a second direction opposite to the first direction.

36. The firing head according to claim 35, wherein the engagement device includes at least one grip member which grips the member and prevents displacement of the member in the first direction relative to the piston.

37. The firing head according to claim 35, wherein the engagement device is attached to, and displaces with, the piston.

38. The firing head according to claim 33, wherein the biasing device is at least one spring.

39. The firing head according to claim 33, wherein the biasing device is at least one chamber having pressurized gas therein.

40. The firing head according to claim 26, wherein the firing mechanism includes a release mechanism and a firing pin, the release mechanism permitting the firing pin to displace when the member is displaced by the displacement mechanism.

41. The firing head according to claim 40, wherein the release mechanism includes at least one collet supported initially by the member, the collet becoming unsupported and thereby permitting the firing pin to displace when the member is displaced by the displacement mechanism.

42. The firing head according to claim 40, wherein the firing pin displaces in response to the pressure level proximate the firing head when the member is displaced by the displacement mechanism.

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