June 26, 1962 H. B. SCHRAMM ET AL 3,040,808

METHOD AND APPARATUS FOR PERFORATING OIL WELLS

Filed Feb. 17, 1959 5 Sheets-Sheet 1

FIG-1

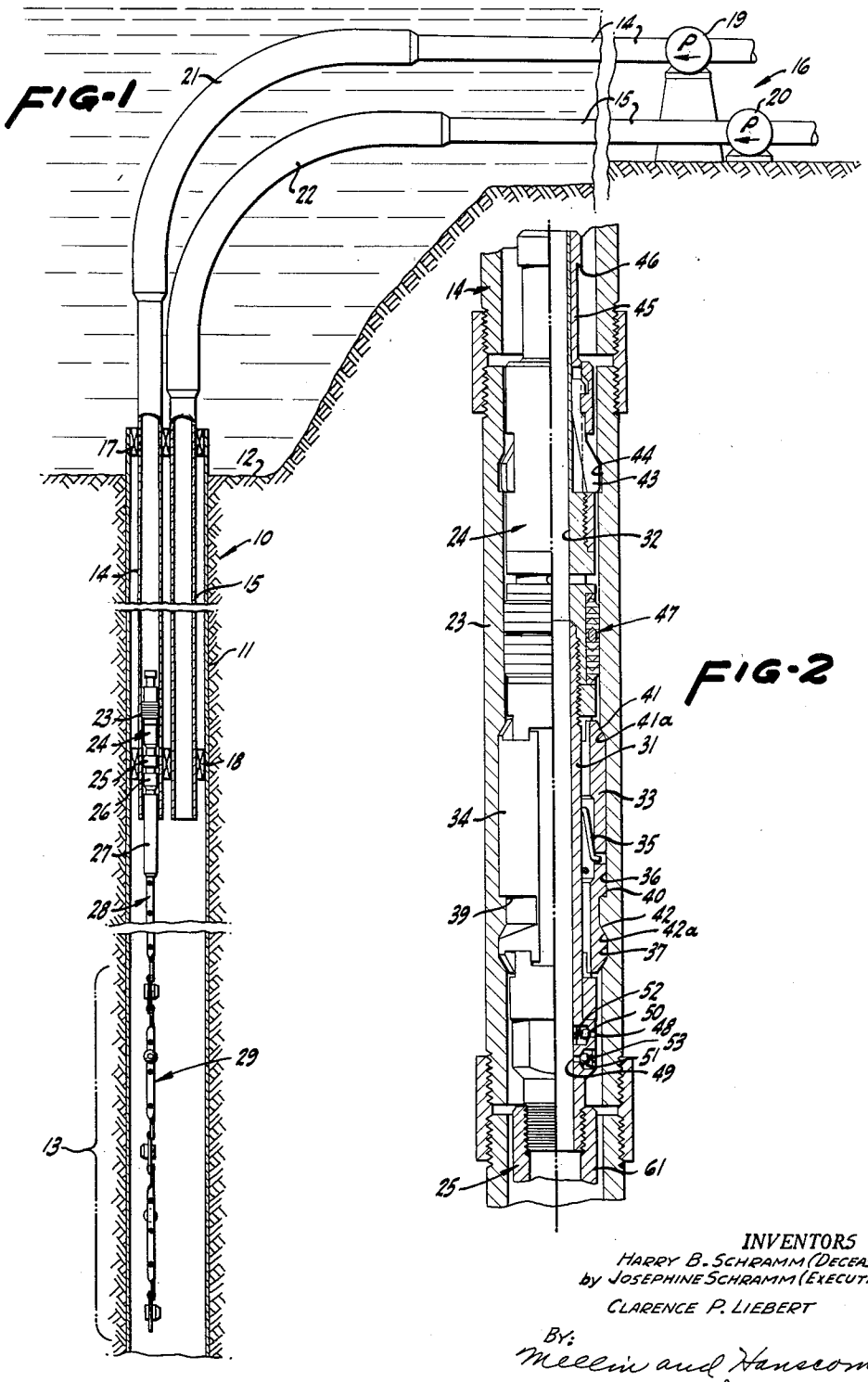


FIG-2

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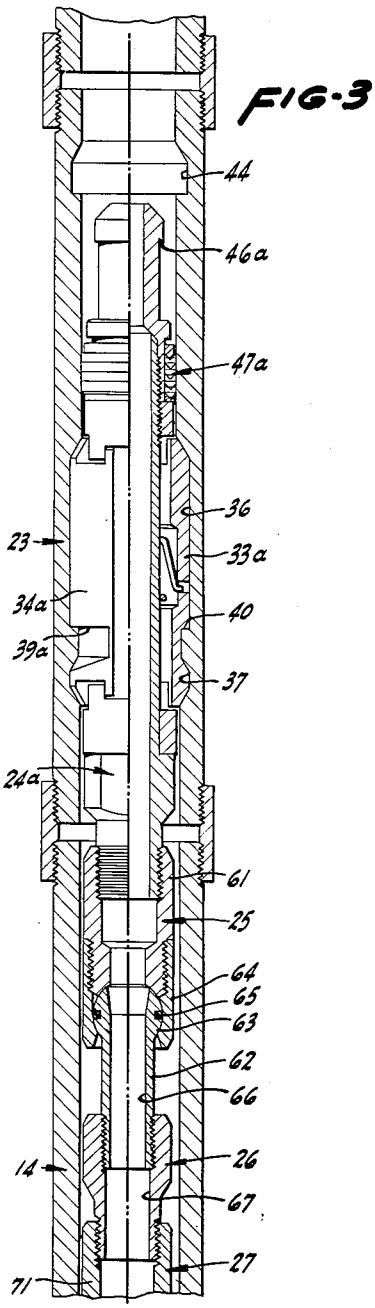
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METHOD AND APPARATUS FOR PERFORATING OIL WELLS

Filed Feb. 17, 1959 5 Sheets-Sheet 2

FIG-3



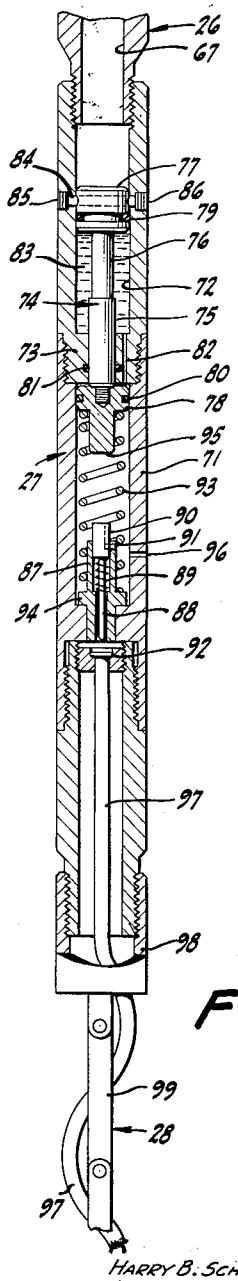


FIG-4

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METHOD AND APPARATUS FOR PERFORATING OIL WELLS

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FIG-5B

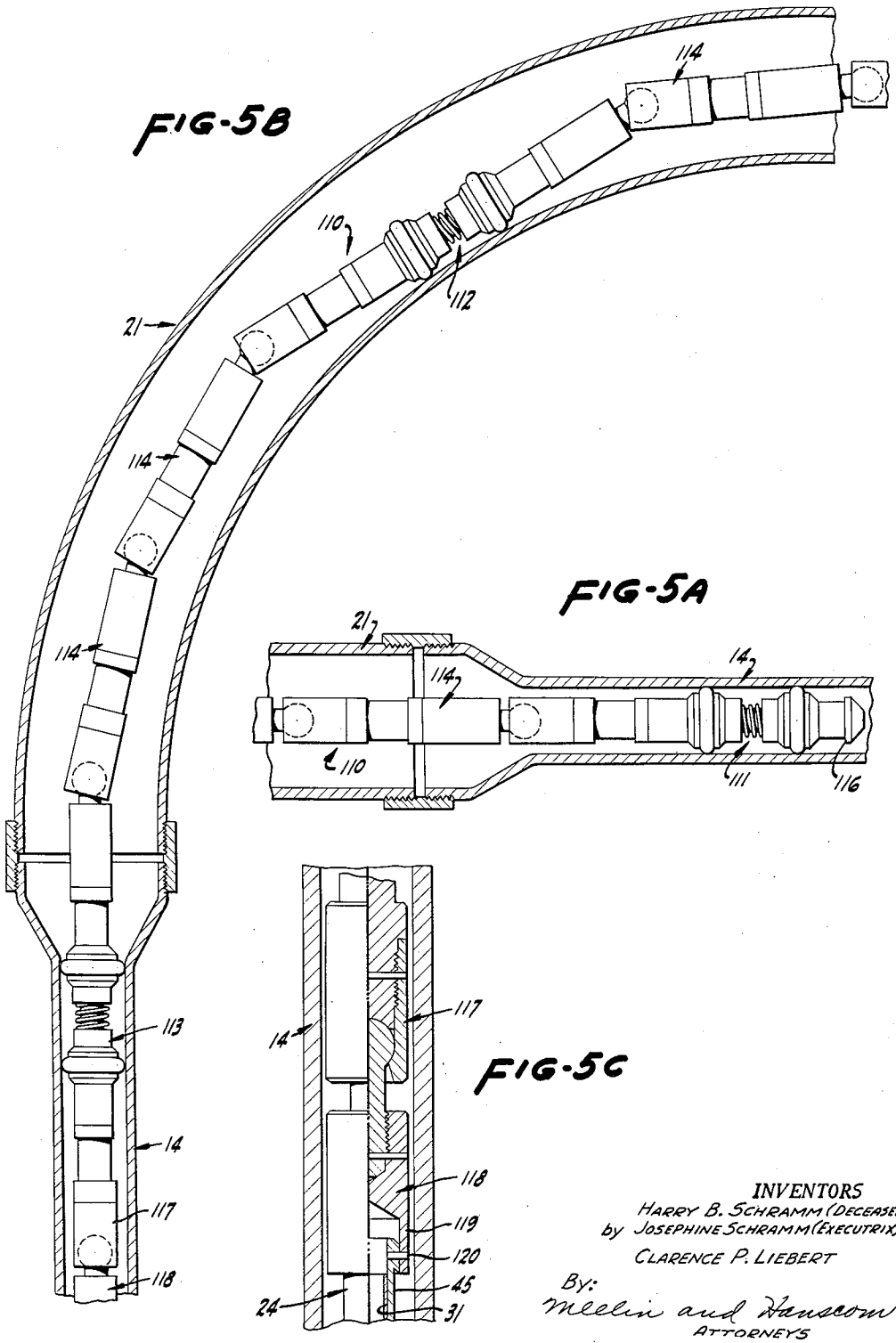


FIG-5A

FIG-5C

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METHOD AND APPARATUS FOR PERFORATING OIL WELLS

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FIG-6

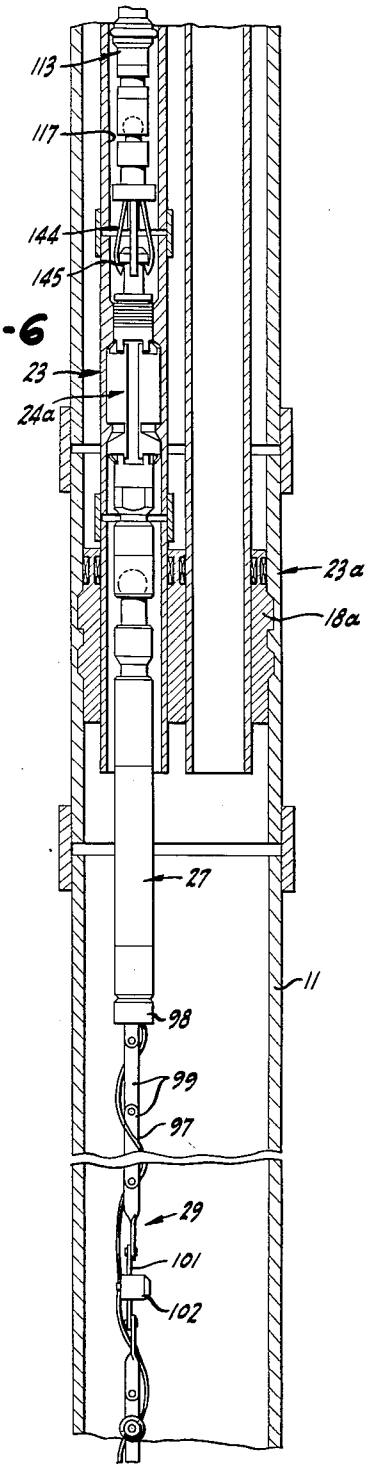
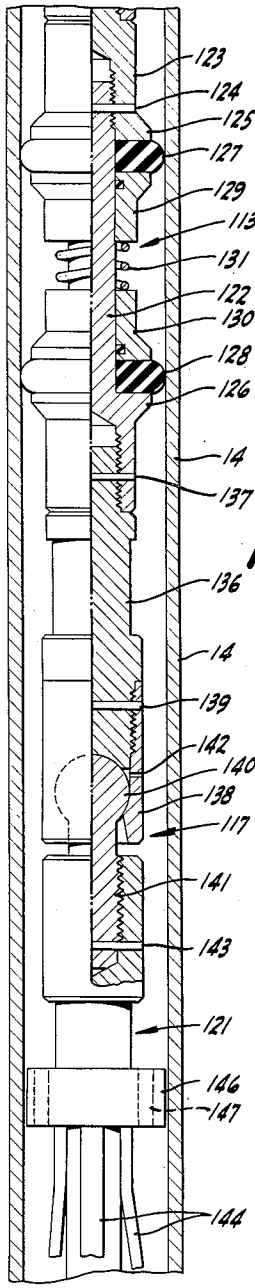


FIG-7



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June 26, 1962 H. B. SCHRAMM ET AL 3,040,808

METHOD AND APPARATUS FOR PERFORATING OIL WELLS

Filed Feb. 17, 1959 5 Sheets-Sheet 5

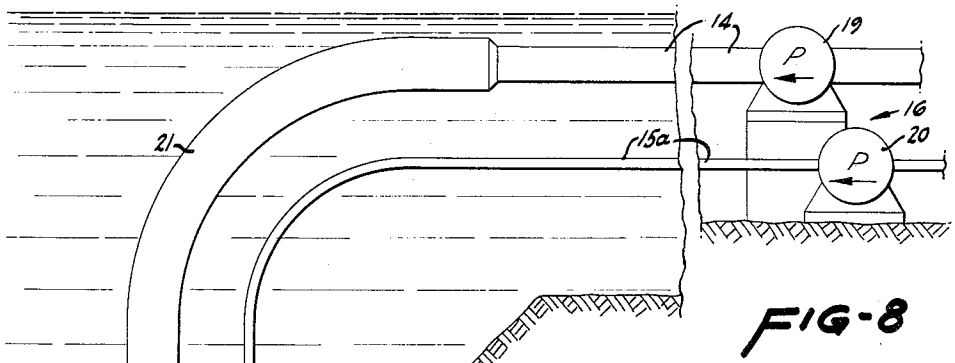
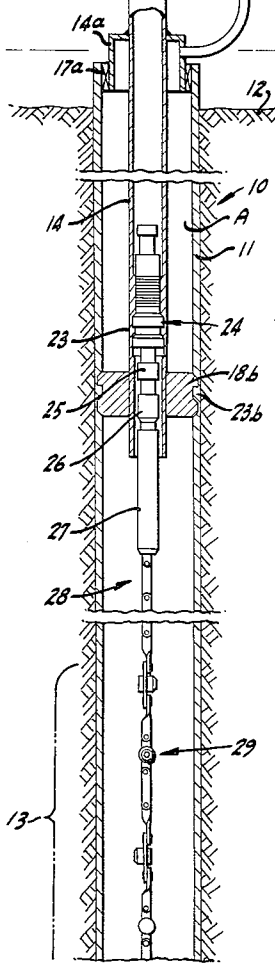


FIG-8



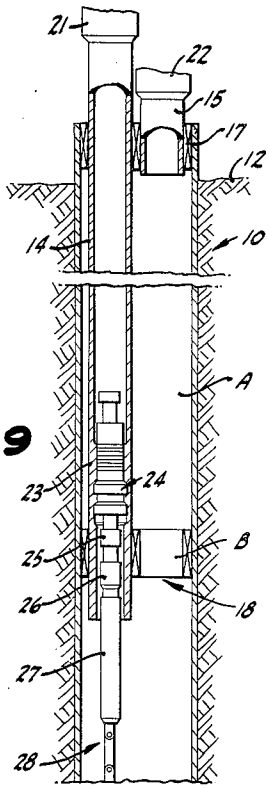


FIG-9

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United States Patent Office 3,040,808 Patented June 26, 1962

3,040,808
METHOD AND APPARATUS FOR PERFORATING OIL WELLS

Harry B. Schramm, deceased, late of Dallas, Tex., by Josephine Schramm, executrix, Dallas, Tex., and Clarence P. Liebert, Dallas, Tex., assignors, by mesne assignments, to Otis Engineering Corporation, Dallas, Tex., a corporation of Delaware

Filed Feb. 17, 1959, Ser. No. 794,218
33 Claims. (Cl. 166—35)

This invention relates to a method and apparatus for perforating oil wells, and has for its primary object the provision of a novel method and means whereby all of the perforating operations are carried out and controlled by fluid pressure exerted in the well from the well head.

Another object is to provide a method and apparatus whereby the perforating means is inserted in the well, landed and locked in place in the well at a desired location therein with a perforating device suspended therefrom and located adjacent a production zone to be perforated, detonated, and removed from the well solely by means of fluid pressure exerted in the well from the well head, and without the use of wire line or similar equipment.

Another object is to provide apparatus for perforating a well which apparatus can be pumped into a well through a tubing string which has one or more curved portions each with a substantially small radius of curvature.

A further object is to provide a detonator operable in response to an extended duration of a fluid pressure of a predetermined magnitude.

Still another object of the invention is to provide a method and apparatus for locating and positioning a perforating device in a well adjacent to a production zone to be perforated.

Other objects and advantages will become apparent in the course of the following detailed description.

In the drawings, forming a part of this application, and in which like parts are designated by like reference numerals throughout the same,

FIG. 1 illustrates schematically a well drilled at a water location with the perforating gun shown suspended from the well tubing and adjacent the production formation to be perforated.

FIG. 2 is a detail view, partly in section, of the extension hanger used in FIG. 1 to suspend the perforator gun in place.

FIG. 3 is a detail view, partly in section, of a modification of the extension hanger shown in FIG. 2, and also showing a sectional view of a ball joint used between the extension hanger and detonator.

FIG. 4 is a sectional view of the detonator used in the assembly shown in FIG. 1.

FIGS. 5A, 5B and 5C are continued elevational views of the flexible plug means used in the present invention to install and remove the perforating assembly in and from the well tubing string by fluid pressure exerted from the well head.

FIG. 6 is a partial view of the system shown in FIG. 1 illustrating a modification of the manner in which the well tubing strings are located and packed to the casing string.

FIG. 7 is an elevational view, partly in section, of a portion of the flexible plug means shown in FIGS. 5A, 5B and 5C, illustrating the details thereof.

FIG. 8 is a generally schematic view, similar to FIG. 1, illustrating a modification of the invention in which the tubing-casing annulus is used as a flow path.

FIG. 9 is a partial view of a system similar to that of

FIG. 8, illustrating another manner in which the tubing-casing annulus is used as a flow path.

In terms of general description, the present invention finds particular use in carrying out well perforating operations in offshore well locations wherein a pair of well tubing strings extends from an onshore well head out to an offshore well and then generally vertically down through the cased bore of the well. One of these tubing strings is provided with a landing nipple made up therein which is spaced above the desired zone of the well to be perforated at a distance therefrom which is determined in a manner to be more fully described.

At the onshore well head, a well perforating device is flexibly connected to an extension hanger and pressure actuated detonator at a distance therefrom equal to the above determined distance from the well zone to the landing nipple. The extension hanger is connected to an elongated flexible plug and the whole assembly is inserted within one of the tubing strings. Fluid pressure is then applied to this tubing string to force the plug through the length thereof, until the extension hanger lands in the landing nipple which prevents further downward movement of the extension hanger in the tubing. The perforating device will now be suspended in the well below the bottom of the tubing string and adjacent the zone of the well to be perforated.

In one embodiment of the invention, the extension hanger is locked against vertical movement in the landing nipple when landed therein. Fluid pressure is then applied from the onshore well head to the other tubing string, which fluid pressure enters the lower end of the first tubing string and disconnects the plug member from the locked in place extension hanger. This same fluid pressure then forces the plug member back through the first tubing string to the well head, where it is removed. Fluid pressure is then reapplied at the well head to the first tubing string at a pressure sufficient to actuate the detonator which in turn causes the perforating device to fire. The plug member is then inserted into the first tubing string, with a pulling, or retrieving, tool connected thereto, and is pumped through the tubing string until the retrieving tool engages the extension hanger. Fluid pressure is again applied at the well head to the second tubing string to force the plug and extension hanger back up through the first tubing string to the well head, to complete the operation.

In another embodiment of the invention, the extension hanger is landed in the landing nipple by pumping the plug member through the first tubing string, as above described, but the extension hanger is not locked in the landing nipple against upward vertical movement therefrom. In this embodiment, the plug member is not removed from the extension hanger before the perforating device is fired. Rather, the fluid pressure in the tubing string is increased, and a fluid by-pass is provided past the plug member so that the increased pressure will actuate the detonator to fire the perforating device. After firing, fluid pressure in applied to the other tubing string to force the plug member and extension hanger back up through the first tubing string to complete the operation.

Referring now to the drawings, and particularly to FIG. 1 thereof, the reference numeral **10** indicates an offshore well having a casing string **11** therein extending downwardly from the water bottom **12** to a production zone **13**. Two tubing strings **14** and **15** extend from an onshore well head location **16** outwardly and generally horizontally along the water bottom **12** to well **10** and then down through the casing **11** to a point therein above production zone **13**. The tubing strings **14** and **15** are packed to the casing **11** by packers **17** and **18** at the top of the casing and at the bottom of the tubing strings.

Pumps 19 and 20 are provided at the well head for the tubing strings 14 and 15, respectively, so that desired fluid pressures may be built up in these strings from the well head. The tubing strings 14 and 15 are each provided with an enlarged internal diameter portion 21 and 22, respectively, bent on a short radius from the top of the casing towards the onshore well head.

The tubing string 14 has a landing nipple 23 made up therein adjacent the bottom thereof, to receive an extension hanger 24 which will be supported therein against downward movement therethrough. A ball joint 25 flexibly connects the extension hanger to a connector member 26, which in turn is connected to the detonator device 27. A flexible link spacer assembly 28 extends downwardly from the detonator housing to a flexible, multiple-gun perforating device 29. The extension hanger 24, shown in detail in FIG. 2, is generally of the type more fully illustrated and described in the Fredd Patent No. 2,798,559, and comprises a main mandrel 31 having a longitudinal bore 32 therethrough. A pair of selector keys 33 and 34 is carried on the main mandrel, the keys being biased outwardly from the mandrel 31 by springs 35. As is seen in FIG. 2, when the extension hanger 24 is landed in landing nipple 23, the selector keys 33 and 34 are biased outwardly into complementary shaped annular grooves 36 and 37. In this position, the engagement of the downwardly facing selector key shoulders 39 with the upwardly facing landing nipple shoulder 40 prevents downward movement of the extension hanger through the landing nipple. Upward movement therefrom is permitted because of the upwardly and inwardly sloping surfaces, 41 and 42, on the selector keys and 41*a* and 42*a* on the landing nipple.

The extension hanger 24 is locked in the landing nipple against upward movement by means of the locking dogs 43 which are moved outwardly into locking grooves 44 of the landing nipple and held therein by downward movement of the locking sleeve 45 relative to the mandrel 31, as fully described in the above referred to Fredd patent. The locking sleeve 45 is provided with an undercut fishing neck 46.

A packing assembly 47 is carried by mandrel 31 for sealing the interface between the extension hanger and landing nipple to prevent fluid flow therebetween.

The extension hanger 24, as described in the Fredd patent, has been modified for use in the present invention by providing two passages, 48 and 49, through the lower end thereof in which ball valves 50 and 51 are disposed to serve as check and relief valves, respectively. Springs 52 and 53 resiliently bias each of these valves to their closed positions. The spring 53 is chosen with a stiffness such that when the fluid pressure within the extension hanger is sufficiently greater than the fluid pressure outside thereof, the ball valve 50 will open, allowing fluid to pass from the inside to the outside of the extension hanger. Similarly, the spring 52 is of a desired stiffness such that when the exterior pressure is sufficiently greater than the interior pressure, ball valve 51 will be unseated to allow fluid flow from the outside to the inside of the extension hanger.

The lower end of the extension hanger 24 is connected to the upper tubular member 61 of ball joint 25. As seen in detail in FIG. 3, a lower tubular member 62, provided with an enlarged spherical head 63, is held against the upper member 61 by retainer 64. The retainer 64 and the lower end of the upper member 61 are shaped complementary to the spherical head 63 to form a socket therefor in which the spherical head may rotate through a limited degree. O-ring 65 prevents fluid flow around the exterior of the spherical head 63. The ball joint 25 has a longitudinal bore 66 therethrough in communication with the extension hanger bore 32. The lower tubular member is secured to the connector member 26, having bore 67 therethrough, which in turn is connected to the upper end of the detonator device 27 housing member 71.

The tubular housing member 71 of the detonator device 27, shown in detail in FIG. 4, has a bore 72 therethrough which is restricted by the inwardly extending annular flange 73. A piston shaft 74 is disposed for longitudinal movement within bore 72 and has the lower portion 75 thereof of greater cross section than that of the upper portion 76 thereof. Piston heads 77 and 78 are formed on shaft 74 and are disposed above and below the annular flange 73, respectively. O-rings 79 and 80 seal the piston heads 77 and 78 to bore 72, respectively, and O-ring 81 seals the lower portion 75 of shaft 74 to flange 73. A small diameter bleed passage 82 extends longitudinally through flange 73. The bore 72 is filled with a suitable hydraulic fluid 83 between piston heads 77 and 78.

A shear pin 84 passes through the housing member 71 and piston head 77 to normally prevent relative longitudinal movement therebetween. Screws 85 and 86 retain the shear pin in place.

A tubular breech 87 is disposed in bore 72 and carries therein a firing pin 88. A spring 89, within the breech, biases the firing pin upwardly therein, with the engagement of breech pin 90 with the bottom of keyway 91 preventing ejection of the firing pin from the breech. The keyway 91 also permits the firing pin to be moved downwardly within the breech so that the lower end of the firing pin may strike the percussion cap 92 therebelow. The firing pin 88 fits rather loosely in breech 87 so that fluid can flow therebetween. In this manner, variations in fluid pressure in the bore 72 below the piston head 78 will not force the firing pin downwardly in the breech.

A compression spring 93, confined between the lower piston head 78 and the breech flange 94, serves both to force the piston head 78 upwardly with a predetermined force and to maintain the breech 87 in place, as shown, so as to space the hammer 95 on piston head 78 from the firing pin 88.

Port 96, through the housing member 71, provides fluid communication between the interior and exterior of the housing member below the piston head 78.

A prima cord 97 extends downwardly from the percussion cap 92 and passes through the bottom connector 98, secured to housing member 71, and which has fixed thereto the link spacer assembly 28.

The link spacer assembly 28 comprises a plurality of pin-connected links 99, made up in any desired overall length, as will be discussed hereinafter, and is used to flexibly space the perforating gun device 29 a desired distance below the extension hanger 24.

The perforating gun device 29, illustrated in FIG. 6, may be any conventional type gun adapted to fire by the ignition of prima cord 97, as, for example, that illustrated and described on page 64 of the September 23, 1957, issue of the Oil and Gas Journal. This perforating device comprises a plurality of pin connected gun carriers 101, each having a charge-containing gun 102 connected thereto. When the prima cord 97 is ignited by the percussion cap 92, all of the guns 102 will be discharged to perforate the casing and the adjacent production zone of the well.

FIGS. 5A, 5B, 5C and 7 illustrate the elongated flexible plug means, indicated generally by the reference numeral 110, used for installing and removing the extension hanger 24 in and from the landing nipple 23. The plug means 110 includes upper, intermediate and lower seal assemblies, 111, 112 and 113, spaced apart from one another by knuckle joint members 114.

As seen in the drawings, the distance between the upper and lower seal assemblies 111 and 113 is greater than the length of the enlarged tubing portion 21 so that by the time that the upper seal assembly 111 enters the enlarged tubing portion 21, the lower seal assembly 113 will already be within the normal diameter portion of tubing string 14, thus maintaining a seal with the tubing string

14 at all times to prevent fluid flow between the flexible plug 110 and the tubing string 14.

The upper seal assembly 111 is provided with an undercut fishing neck 116 in the event that it be desired to connect auxiliary equipment thereto. The lower seal assembly 113 has a knuckle joint connection 117 to a running tool 118 used for running the extension hanger into the well.

The running tool 118, illustrated in FIG. 5C, has a depending skirt 119 adapted to surround the locking sleeve 45 of the extension hanger 24, to which it is releasably connected, as by shear pin 120, for a purpose to be hereinafter described. Although the running tool 118 has been illustrated in one specified form in FIG. 5C, it is to be realized that any commercially available running tool usable with the extension hanger 24 may be substituted for that shown.

FIG. 7 illustrates the constructional details of the lower seal assembly 113 and the ball and socket connection 117, and also shows a pulling, or retrieving, tool 121 connected to the flexible plug means 110. The seal assembly 113 comprises a solid body member 122 having an upper sub 123 connected thereto and maintained in place by roll pin 124 so that the body member and upper sub constitute essentially an integral part. Upper and lower annular shoulders 125 and 126 are provided as rigid stop members for the annular resilient seal members 127 and 128. Collars 129 and 130 surround the body 122 and are compressed against the seal members 127 and 128 by spring 131 to force the outer peripheries thereof outwardly into sealing engagement with the inner wall of the tubing string 14.

The upper sub 136 of the knuckle joint 117 is connected to the body member 122 of the seal assembly 113 and held in place therein by roll pin 137. The lower end of the upper sub 136 has secured thereto a ball retainer 138 which is maintained in place by roll pin 139.

The lower end of the upper sub 136 and the interior of retainer 138 are shaped complementary to the spherical head 140 on the upper end of stem member 141, which spherical head may rotate therein through a limited degree. A port 142 is formed through the retainer 138 above the stem head 140.

The pulling tool 121 is connected to stem member 141 and is held secured thereto by roll pin 143. The pulling tool, illustrated in FIGS. 6 and 7, has a plurality of resilient fingers 144 thereon provided with upwardly and inwardly extending hooks 145 which are adapted to engage the undercut fishing neck 46 of extension hanger 24. A centralizing ring 146 is provided on the pulling tool for centering the fingers 144 in the tubing 14 so that they may grapple the extension hanger fishing neck, and longitudinal passages 147 are provided through this ring to permit fluid flow therethrough.

The seal assemblies 111 and 112 are identical in construction to the above described construction of seal assembly 113, and the knuckle joints 114 are generally identical in construction to knuckle joint 117.

In the operation of the equipment thus far described, it is assumed that the well 10 has been cased, and that both of the tubing strings have been installed therein, as illustrated in FIG. 1. After the tubing has been installed and packed in place by packer 18, a casing collar log is run, to determine the distance between the production zone 13 to be perforated and the bottom of the tubing string 14. This distance, plus the known distance from the bottom of tubing string 14 and the landing nipple 23 therein, gives the overall distance from the production zone to the landing nipple.

The perforating assembly is then made up at the onshore well head, with the link spacer assembly 28 made up of sufficient links to space the perforating gun device 29 a distance from the extension hanger 24 equal to the above mentioned overall distance from the production zone to the landing nipple 23. The extension hanger 24 is then connected by the running tool 118 to the flexible plug means 110, and the entire assembly is inserted into the tubing string 14.

Fluid pressure is then applied to the tubing string 14 by pump 19 with sufficient force to move the entire assembly through the tubing until the extension hanger 24 finally rests in landing nipple 23. The flexibility of the perforating gun device 29, the spacer link assembly 28, the ball joint connection 25 between the detonator 27 and extension hanger 24, the knuckle joint 117 between the running tool 118 and the sealing assembly 113, and the various knuckle joints 114 of the flexible plug means 110 permit the entire assembly to pass through the short radius bend of the enlarged diameter portion 21 of tubing string 14, as well as through any other deviated portion of the tubing string 14. The tubing string 15 is open at the top and bottom thereof during this operation to relieve any pressure in the well built up as a result of pumping the above elements down through tubing string 14.

With the extension hanger landed in place in the landing nipple 23, the fluid pressure built up in tubing string 14 by pump 19 forces the plug means 110 downwardly with sufficient force to move the extension hanger locking sleeve 45 downwardly relative to mandrel 31 which moves the locking dogs 43 outwardly into locked position in landing nipple groove 44. Additional fluid pressure in tubing string 14 causes the running tool shear pin 120 to shear, freeing the running tool from the extension hanger, which is now locked in place in the landing nipple.

At this time, the perforating gun device 29 is suspended from the extension hanger and is adjacent the production zone 13 to be perforated.

Pump 19 is now disconnected from tubing string 14, and fluid pressure is built up in tubing string 15 by pump 20. This fluid pressure is now greater than that within the extension hanger 24, causing check valve 50 to open, and allowing fluid to flow into the extension hanger and upwardly against the bottom sealing assembly 113 of the now disconnected flexible plug means. The pressure differential on the plug will then cause it to be pumped back up through the tubing string 14 to the well head, so that it may be removed.

It will be noted that this fluid pressure within tubing string 14 will not affect the detonator 27 because the pressure exerted downwardly on piston head 77 is balanced by the same pressure acting through port 96 upwardly on piston head 78.

After removal of the flexible plug, pump 19 is again used to build up pressure within tubing string 14. This pressure will be exerted on the upper face of the detonator piston head 77, and when sufficient pressure is applied, shear pin 84 will fail, freeing piston shaft 74 for downward movement. Maintaining this pressure causes the piston head 77 to move downwardly and force fluid 83 through the bleed passage 82 into the space between flange 73 and piston head 78.

The piston head continues to move downwardly slowly until the upper shoulder of the piston shaft portion 74 passes below O-ring 81, whereupon the hydraulic fluid 83 is allowed to pass through the main bore of the flange 73 into the space between the flange and the lower piston head 78 more rapidly, thus allowing the piston assembly to surge downwardly. This causes the hammer 95 on the lower end of piston head 78 to strike the upper end of the firing pin 88, whereupon the lower end of the firing pin strikes the upper end of the percussion cap which explodes and ignites the prima cord 97. When the prima cord is ignited, the perforator 29 is discharged practically simultaneously. It is to be noted that the fluid pressure 82 is merely of sufficient size to permit the piston assembly to move slowly downwardly and that the piston assembly does not surge until the enlarged diameter shaft portion 75 passes below the O-ring 81. Also, spring 93 offers little opposition to the downward

movement of the piston assembly but is employed primarily for the purpose of maintaining the breech **87** in its downward position. The shock waves created by the discharging of the perforator are dissipated upwardly through the circulating tubing string **15**, thus causing relatively little injury to the tools, tubing, casing and packers.

It is to be noted that spring **93** serves to maintain separation between the piston head **78** and firing pin **88** in the event that shear pin **84** fails and the hydraulic fluid leaks from the reservoir in which it is contained, until a predetermined force is exerted on the piston head **77**.

It is also to be noted that the primary safety feature of the detonator consists of the size of the bleed passage **82** and the flange **73** arrangement which operates as follows: Should the pressure be increased in tubing string **14** inadvertently, thus shearing the pin **84**, a predetermined minimum time will be necessary in order for the piston assembly to cause the percussion cap **92** to be discharged as previously described. Therefore, if the pressure is inadvertently built up from the surface for any reason, a minimum time will be allowed in which to correct the error. It is to be further noted that after the shear pin **84** is sheared, the time required to cause firing will vary, depending upon the pressure exerted on the upper end of the piston assembly. The two are proportional. The size of the bleed passage, the viscosity of the hydraulic fluid **83** and its temperature, all enter into the time required for the piston firing pin to strike the percussion cap with a given pressure exerted on the piston head **77** from above.

After perforation, a pulling tool **121** is connected to the flexible plug means **110** and this assembly is inserted into tubing string **14** and pumped downwardly therethrough by the pressure exerted by pump **19**, to engage the fishing neck **46** of the extension hanger. During this downward passage of the plug means, the fluid in tubing **14** below the plug means is forced out through the relief valve **51** in the extension hanger and back up tubing string **15**. The relief valve **51** is biased to closed position by spring **53** with sufficient force such that a greater internal pressure is required to open the valve than is necessary to shear the shear pin **84** in the detonator.

After engagement of the pulling tool **121** with the extension hanger **24**, fluid pressure is again built up in tubing string **15**, which again causes check valve **50** to open, so that the pressurized fluid will exert a force underneath the flexible plug, which causes the flexible plug to move upwardly. This in turn pulls the locking sleeve **45** of the extension hanger upwardly, freeing the locking dogs **43** for movement from the locking groove **44**, and allows the extension hanger to be moved upwardly from the landing nipple. Once the extension hanger sealing means **47** clears the landing nipple, fluid flow may take place between the extension hanger and tubing string to be exerted on the lower side of the flexible plug.

The flexible plug, extension hanger, detonator and the unexpended parts of the perforating gun device are then pumped through tubing string **14** back up to the onshore well head, from where they are removed, to complete the operation.

In the foregoing description of operations, it will be noted that a casing collar log had to be run after the tubing was installed, in order to determine the distance between the production zone and landing nipple **23** so that the spacer link assembly **28** could be made up accordingly.

FIG. 6 illustrates a manner in which the necessity for this log is eliminated. During the initial casing of the well, a casing landing nipple **23***a* is made up in the casing string **11**, which landing nipple is generally similar to the tubing landing nipple **23**, and which has an internal profile adapted to receive the packer **18***a* therein. Since the particular details of the casing landing nipple **23***a* and a tubing-casing packer **18***a* landable therein form no part of the invention other than their use therewith, these elements have only been indicated schematically. Any commercially available elements usable for this purpose may be used, such as those shown on page 4136 of the Composite Catalog of Oil Field Equipment and Service, 1957 edition.

After the casing string has been installed, the usual casing collar log which is run after casing installation, will indicate the distance from the production zone **13** to the casing landing nipple **23***a*. Prior to installation of the tubing strings **14** and **15**, the tubing string **14** is made up with the packer **18***a* and landing nipple **23** therein, at a known distance apart. The tubing string **14** is then run into the casing until the packer **18***a* is landed in the casing landing nipple **23***a*, and the packer is set to seal between the tubing and casing. Tubing string **15** is then run into the casing and packed to the other bore of the packer **18***a* by conventional methods to complete the installation.

With this installation, the distance from the production zone **13** to the tubing landing nipple **23** is the sum of the known distances from the production zone to the casing landing nipple **23***a* and from the packer **18***a* to the tubing landing nipple **23**, and thus there is no need for a further casing collar log after the tubing is installed to find the overall distance from the production zone **13** and the tubing landing nipple **23**.

There are also various times in which it is not necessary that the extension hanger be locked in the landing nipple or that the flexible plug means **110** be removed from the well after installing the extension hanger and before firing the perforating device.

In these instances, a modified extension hanger **24***a*, illustrated in FIGS. 3 and 6, is employed. The extension hanger **24***a* is generally the same as extension hanger **24** previously described, in that it has selector keys **33***a* and **34***a* spring biased outwardly into the landing nipple grooves **36** and **37**, which keys have a downwardly facing shoulder **39***a* engageable with landing nipple shoulder **40** to prevent downward movement of the extension hanger through the landing nipple. Sealing means **47***a*, carried by the extension hanger, seals against the landing nipple.

Extension hanger **24***a* has been modified from that previously described in that no locking dogs **43** are used to lock into landing nipple groove **44**, and that the check and relief valves **50** and **51** are eliminated.

In the operation of the invention, using extension hanger **24***a*, the same initial preparations are made, as previously described, and the flexible plug means **110** is connected to the extension hanger by a pulling tool **121** engaging the fishing neck **46***a* of the extension hanger, or by some other permanent connection. The entire assembly is then pumped down the tubing string **14**, until the extension hanger **24***a* is landed in landing nipple **23**, with the detonator **27** and perforating gun device **29** suspended therebelow.

The fluid pressure in tubing string **14** is then increased by pump **19**. When the pressure is sufficiently high, it will overcome the force exerted on the sealing elements **127** and **128** of the plug means by springs **131** which compress the sealing elements against the tubing, and will force fluid past these sealing elements and through the extension hanger **24***a* and ball joint **25** to be exerted on the piston head **77** in the detonator. The force of this high fluid pressure will again cause shear pin **84** to shear to actuate the detonator as previously described.

After firing of the perforator, fluid pressure is built up in tubing string **15**, which pressure is exerted on the exterior of the extension hanger **24***a*, forcing it upwardly into tubing string **14**. Once the seal between the extension hanger **24***a* and the landing nipple **23** is broken, the fluid pressure will be exerted on the flexible plug means **110** causing it to move upwardly through the tubing string

14 to the well head, carrying the extension hanger 24*a*, detonator 27 and the unexpanded portions of the perforator 29. These elements are then removed from the tubing string to complete the operations.

FIG. 8 illustrates a modification of the invention in which the tubing string 14 is used as one flow path, and the tubing-casing annulus A is used as the other flow path.

The tubing string 14 is anchored to the casing string 11 by means of a tubing anchor 18*b* fixed in the tubing string and landable in the casing landing nipple 23*b*. The tubing anchor 18*b* may be any commercially available element usable for this purpose, again such as the casing packer shown on page 4136 of the Composite Catalog of Oil Field Equipment and Services, 1957 edition, however with the packing elements removed. The tubing anchor 18*b* does not seal the tubing string 14 to the casing 11, and thus fluid flow may take place in the tubing-casing annulus A past the tubing anchor 18*b*.

The upper end of the casing string 11 is sealed by packer 17*a* to the flange 14*a* of the tubing string 14, and conduit 15*a* extends from the tubing-casing annulus A to the onshore pump 20.

The method of operation is the same in this modification as that previously described, that is, the perforating apparatus is again made up as described above and is pumped through tubing string 14 by pump 19 until the extension hanger 24 lands in landing nipple 23. The detonator 27 is again actuated in response to the fluid pressure created by pump 19 to fire the perforating gun device 29 to perforate the production zone 13 of the well.

The perforating apparatus is removed by fluid pressure created by pump 20 which pumps fluid through conduit 15*a*, through the tubing-casing annulus A past the tubing anchor 18*b* and up through tubing string 14. The removal of the perforating apparatus thus occurs in the same manner as previously discussed.

FIG. 9 illustrates another modification by which the tubing-casing annulus A is used as a flow path. In this modification, the tubing string 14 is anchored to the casing string by a dual bore packer 18, as in FIG. 1. Or, if desired, a dual bore tubing-casing packer of the type shown in FIG. 6 may be used.

The tubing string 15 is sealed to the top of the casing string by packer 17, as in FIG. 1, but does not extend down in the casing string to packer 18, as previously described.

In operation, the perforating apparatus is again pumped through tubing string 14 and landed in the tubing landing nipple 23. In removal, fluid is pumped through tubing string 15, through the tubing-casing annulus A, through bore B of packer 18 and up through the tubing string 14.

Thus, the only significant difference between the modifications of FIGS. 8 and 9 and the forms earlier described, is that the tubing-casing annulus is used as a flow path in place of tubing string 15 within the casing string. The selection of the system to use will be determined primarily by the necessity of fluidly separating the production zone 13 from the zones above packer 18. If separation is not necessary or desired, then the systems of FIGS. 8 and 9 may be used. If separation is necessary, then tubing string 15 must extend down to below packer 18, with packer 18 being used to seal the tubing strings 14 and 15 to the casing 11.

Thus, by means of the present invention, well perforating operations can be completely carried out without the use of wire line or similar devices, with all of the operations being performed and controlled by regulating the fluid pumps 19 and 20 at the onshore well head to provide the desired fluid pressure in the two tubing strings.

It is to be further realized that the methods and apparatus described are preferred embodiments of the invention and that various changes may be made in the shape, size and arrangement of parts without departing from the spirit of the invention or the scope of the attached claims.

Having thus described our invention, what we claim and desire to secure by Letters Patent is:

1. A method for perforating a desired zone of an oil well having a fluid flow path extending from the well head of said well down to above said zone and in which said fluid flow path has a point therein spaced a known distance above said zone, comprising: connecting a well perforator to a plug at a distance therebetween equal to said known distance, forcing said well perforator and plug down through said fluid flow path by fluid pressure in said flow path exerted from said well head, arresting downward movement of said plug in said fluid flow path at said point therein with said well perforator suspended therebelow, and detonating said well perforator in response to an increase in fluid pressure exerted in said fluid flow path from said well head.

2. A method for perforating a desired zone of an oil well having two separate fluid flow paths extending from the well head of said well down to above said zone and in which one of said fluid flow paths has a point therein spaced a known distance above said zone, comprising: connecting a well perforator to a plug at a distance therebetween equal to said known distance, pumping said well perforator and plug down through said one fluid flow path by fluid pressure in said one flow path exerted from said well head, arresting downward movement of said plug in said one fluid flow path at said point therein with said well perforator suspended therebelow, detonating said well perforator in response to a fluid pressure exerted in said first fluid flow path from said well head, pumping fluid under pressure down the other of said fluid flow paths, and forcing said plug back up through said one fluid flow path by said last named fluid.

3. A method for perforating a desired zone of an oil well having two separate fluid flow paths extending from the well head of said well down to above said zone and in which one of said fluid flow paths has a point therein spaced a known distance above said zone, comprising: connecting a well perforator to a plug at a distance therebetween equal to said known distance, pumping said well perforator and plug down through said one fluid flow path by fluid pressure in said one flow path exerted from said well head, landing said extension hanger in said one fluid flow path at said point therein with said well perforator suspended therebelow, increasing the fluid pressure in said one flow path, detonating said well perforator in response to an extended duration of said increased fluid pressure, pumping fluid under pressure from said well head down the other of said fluid flow paths, and forcing said plug back up through said one fluid flow path by said last named fluid.

4. A method for perforating oil wells comprising installing a well casing string having a landing nipple made up therein in said well, logging the distance from a desired zone of perforation to said casing landing nipple, making up a tubing string having a casing packer and a landing nipple made up therein at a predetermined spacing from one another, installing the tube string in the casing string to land the packer in the casing landing nipple, connecting a well perforator to an extension hanger at a distance therefrom equal to the distance from said desired zone of perforation to said casing landing nipple plus the distance that said tubing landing nipple is above said packer, pumping said well perforator and extension hanger down through said tubing string by fluid pressure exerted in said tubing string from the upper end thereof, landing said extension hanger in said tubing landing nipple, and detonating said well perforator by said fluid pressure.

5. A method for perforating oil wells, comprising: installing a well casing string having a landing nipple made up therein in said well, logging the distance from a de-

sired zone of perforation to said casing landing nipple, making up a tubing string having a casing packer and a landing nipple made up therein at a predetermined spacing from one another, installing the tubing string in the casing string to land the packer in the casing landing nipple, connecting a well perforator to an extension hanger at a distance therefrom equal to the distance from said desired zone of perforation to said casing landing nipple plus the distance that said tubing landing nipple is above said packer, pumping said well perforator and extension hanger down through said tubing string by fluid pressure exerted in said tubing string from the upper end thereof, landing said extension hanger in said tubing landing nipple, increasing the fluid pressure in said tubing string from the upper end thereof, detonating said well perforator after a predetermined interval while maintaining the increase of fluid pressure in said tubing string, pumping said extension hanger back up through said tubing string by fluid pressure exerted in said tubing string from the lower end thereof.

6. A method of perforating an oil well having a zone to be perforated and a casing therein, comprising: forming first and second fluidly separated fluid flow paths within said casing from the well head of said well down to above said zone with a landing nipple made up in said first fluid flow path and with said second fluid flow path being in fluid communication with said first fluid flow path below the landng nipple therein, connecting a well perforating device to an extension hanger at a distance therefrom equal to the distance between the zone to be perforated and the first fluid flow path landing nipple, pumping the perforating device and extension hanger from the well head down through said first fluid flow path by fluid pressure exerted from said well head, landing the extension hanger in the first fluid flow path landing nipple with the well perforating device suspended therebelow, increasing the fluid pressure within said first fluid flow path, and detonating said well perforating device in response to a fluid pressure of a predetermined amount within said first fluid flow path exerted therein from said well head.

7. A method of perforating an oil well having a zone to be perforated and a casing therein, comprising: forming first and second fluidly separated fluid flow paths within said casing from the well head of said well down to above said zone with a landing nipple made up in said first fluid flow path and with said second fluid flow path being in fluid communication with said first fluid flow path below the landing nipple therein, packing said fluid paths above the lower ends thereof to said casing, connecting a well perforating device to an extension hanger at a distance therefrom equal to the distance between the zone to be perforated and the first fluid flow path landing nipple, pumping the perforating device and extension hanger from the well head down through said first fluid flow path by fluid pressure exerted from said well head, landing the extension hanger in the first fluid flow path landing nipple with the well perforating device suspended therebelow, detonating said well perforating device in response to an extended duration of the presence of a fluid pressure of a predetermined amount within said first fluid flow path exerted therein from said well head, pumping fluid under pressure from said well head down through said second fluid flow path, and forcing said extension hanger back up through said first fluid flow path to said well head.

8. A method of perforating an oil well having a casing therein provided with a landing nipple spaced a known distance above a desired zone to be perforated, comprising: forming first and second fluidly separated fluid flow paths within said casing from the well head of said well down to said casing landing nipple with a landing nipple in said first fluid flow path spaced a known distance from said casing landing nipple and with said second fluid flow path being in fluid communication with said first fluid flow path below the landing nipple therein, connecting a well perforating device to an extension hanger at a distance therefrom equal to the distance between the zone to be perforated and the first fluid flow path landing nipple, pumping the perforating device and extension hanger from the well head down through said first fluid flow path by fluid pressure exerted from said well head, landing the extension hanger in the first fluid flow path landing nipple with the well perforating device suspended therebelow, and detonating said well perforating device in response to a fluid pressure of a predetermined amount within said first fluid flow path exerted therein from said well head.

9. A method of perforating an oil well having a casing therein provided with a landing nipple spaced a known distance above a desired zone to be perforated, comprising: forming first and second fluidly separated fluid flow paths within said casing from the well head of said well down to said casing landing nipple with a landing nipple in said first fluid flow path spaced a known distance from said casing landing nipple and with said second fluid flow path being in fluid communication with said first fluid flow path below the landing nipple therein, connecting a well perforating device to an extension hanger at a distance therefrom equal to the distance between the zone to be perforated and the first fluid flow path landing nipple, pumping the perforating device and extension hanger from the well head down through said first fluid flow path by fluid pressure exerted therein from said well head, landing the extension hanger in the first fluid flow path landing nipple with the well perforating device suspended therebelow, detonating said well perforating device by a fluid pressure of a predetermined amount within said first fluid flow path exerted therein from said well head, pumping fluid under pressure from said well head down through said second fluid flow path, and forcing said extension hanger back up through said first fluid flow path to said well head by said last named fluid under pressure.

10. A method of perforating an oil well having a casing therein provided with a landing nipple spaced a known distance above a desired zone to be perforated, comprising: forming first and second fluidly separated fluid flow paths within said casing from the well head of said well down to said casing landing nipple with a landing nipple in said first fluid flow path spaced a known distance from said casing landing nipple and with said second fluid flow path being in fluid communication with said first fluid flow path below the landing nipple therein, connecting a well perforating device to an extension hanger at a distance therefrom equal to the distance between the zone to be perforated and the first fluid flow path landing nipple, pumping the perforating device and extension hanger from the well head down through said first fluid flow path by fluid pressure exerted from said well head, landing the extension hanger in the first fluid flow path landing nipple with the well perforating device suspended therebelow, increasing the fluid pressure within said first fluid flow path from said well head, detonating said well perforating device in response to an extended duration of the presence of increased fluid pressure within said first fluid flow path, pumping fluid under pressure from said well head down through said second fluid flow path, and forcing said extension hanger back up through said first fluid flow path to said well head by said last named fluid under pressure.

11. Apparatus for perforating a desired zone of a well bore comprising a casing string lining said well bore, a tubing string extending down through said casing string with the lower end of said tubing string being above said zone, a landing nipple in said tubing string, a tubular extension hanger movable through said tubing string and removably landed in said landing nipple, an elongated flexible plug means pumpable through said tubing string by a fluid pressure therein, means connecting said plug means to said extension hanger, a well perforating gun, means suspending said perforating gun from said ex-

tension hanger at a distance therebelow approximately equal to the distance from said zone to said landing nipple whereby said perforator device is suspended adjacent said zone, a detonator housing member connected to said extension hanger for movement therewith, means providing fluid communication between the interiors of said detonator housing member and said extension hanger, means responsive to the presence of a predetermined high fluid pressure for providing fluid flow through said first tubing string from above said plug means to the interior of said extension hanger, fluid pressure actuated detonator means in said detonator housing, and means responsive to actuation of said detonator for firing said perforating gun.

12. Apparatus for perforating a desired zone of a well bore comprising a casing string lining said well bore, first and second tubing strings extending down through said casing string with the lower ends of said tubing strings being above said zone, packer means for sealing said tubing strings to said casing string, a landing nipple in said first tubing string, said first tubing string being open from below the landing nipple therein to the interior of said casing string below said packer means and said second tubing string being also open to the interior of said casing string, below said packer means, a tubular extension hanger movable through said first tubing string and removably landed in said landing nipple, means sealing the exterior of said extension hanger to said landing nipple to prevent fluid flow therebetween, an elongated flexible plug means pumpable through said first tubing string by a fluid pressure therein and disposed in said tubing string above said extension hanger, means connecting said plug means to said extension hanger, a well perforating gun, means suspending said perforating gun from said extension hanger at a distance therebelow equal to the distance from said zone to said landing nipple whereby said perforating gun is suspended adjacent said zone, a detonator housing member connected to said extension hanger for movement therewith, means providing fluid communication between the interiors of said detonator housing member and said extension hanger, means responsive to the fluid pressure within said first tubing string exerted on said plug and operable to provide fluid flow through said first tubing string from above said plug means to the interior of said extension hanger when said fluid pressure within said first tubing string exerted on said plug is above a predetermined value, fluid pressure actuated detonator means in said detonator housing, and means responsive to actuation of said detonator means for firing said perforating gun.

13. Apparatus for perforating a desired zone of a well bore comprising a casing string lining said well bore, a landing nipple in said casing string above said zone, first and second tubing strings extending down through said casing string with the lower ends of said tubing strings being above said zone and below said casing string landing nipple, packer means fixed to said first tubing string and landed in said casing string landing nipple to seal said tubing strings to said casing string, a landing nipple in said first tubing string, said first tubing string being open from below the landing nipple therein to the interior of said casing string below said packer means and said second tubing string being also open to the interior of said casing string below said packer means, a tubular extension hanger movable through said first tubing string and removably landed in said first tubing string landing nipple, means sealing the exterior of said extension hanger to said first tubing string landing nipple to prevent fluid flow therebetween, an elongated flexible plug means pumpable through said first tubing string by a fluid pressure therein, means connecting said plug means to said extension hanger, a well perforating gun, means suspending said perforating gun from said extension hanger at a distance therebelow approximately equal to the distance from said zone to said first tubing string landing nipple whereby said perforating gun is suspended adjacent said zone, a detonator housing member flexibly connected to said extension hanger for movement therewith, means providing fluid communication between the interiors of said detonator housing member and said extension hanger, means responsive to the fluid pressure within said first tubing string exerted on said plug and operable to provide fluid flow through said first tubing string from above said plug means to the interior of said extension hanger when said fluid pressure within said first tubing string exerted on said plug is above a predetermined value, a percussion cap in said detonator housing, hammer means within said detonator housing responsive to an extended duration of the presence of said predetermined fluid pressure therein to strike said percussion cap, and means responsive to the striking of said percussion cap for firing said perforating gun.

14. Apparatus for perforating a desired zone of a well bore comprising a casing string lining said well bore, a tubing string extending down through said casing string with the lower end of said tubing string being above said zone, a landing nipple in said tubing string, a tubular extension hanger movable through said tubing string and removably landed in said landing nipple, a plug means pumpable through said tubing string by a fluid pressure therein, means detachably connecting said plug means to said extension hanger, means including a check valve for allowing fluid flow from the exterior of said extension hanger to the interior thereof, a well perforating gun, means suspending said perforating gun from said extension hanger at a distance therebelow approximately equal to the distance from said zone to said tubing string landing nipple, a detonator housing member connected to said extension hanger, means providing fluid communication between the interiors of said detonator housing member and said extension hanger, fluid pressure actuated detonator means in said detonator housing, means responsive to actuation of said detonator for firing said perforating gun, and means including a relief valve to provide fluid flow from the interior of said extension hanger to the exterior thereof.

15. Apparatus for perforating a desired zone of a well bore comprising a casing string lining said well bore, first and second tubing strings extending down through said casing string with the lower ends of said tubing strings being above said zone, packer means for sealing said tubing strings to said casing string, a landing nipple in said first tubing string, said first tubing string being open from below the landing nipple therein to the interior of said casing string below said packer means and said second tubing string string being also open to the interior of said casing string below said packer means, a tubular extension hanger movable through said first tubing string and removably landed in said landing nipple, means sealing the exterior of said extension hanger to said landing nipple to prevent fluid flow therebetween, an elongated flexible plug means pumpable through said first tubing string by a fluid pressure therein, means detachably connecting said plug means to said extension hanger thereabove, means including a check valve for allowing fluid flow from the exterior of said extension hanger below said sealing means to the interior of said extension hanger, a well perforating gun, means suspending said perforating gun from said extension hanger at a distance therebelow equal to the distance from said zone to said landing nipple, a detonator housing member connected to said extension hanger for movement therewith, mans providing fluid communication between the interiors of said detonator housing member and said extension hanger, fluid pressure actuating detonator means in said detonator housing, means responsive to actuation of said detonator means for firing said perforating gun, and means including a relief valve to provide fluid flow from the interior of said extension hanger to the exterior thereof below said sealing means.

16. Apparatus for perforating a desired zone of a well

bore comprising a casing string lining said well bore, a landing nipple in said casing string above said zone, first and second tubing strings extending down through said casing string with the lower ends of said tubing strings being above said zone and below said casing string landing nipple, packer means fixed to said first tubing string and landed in said casing string landing nipple to seal said tubing strings to said casing string, a landing nipple in said first tubing string, said first tubing string being open from below the landing nipple therein to the interior of said casing string below said packer means and said second tubing string being also open to the interior of said casing string below said packer means, a tubular extension hanger movable through said first tubing string and removably landed in said first tubing string landing nipple, means sealing the exterior of said extension hanger to said first tubing string landing nipple to prevent fluid flow therebetween, an elongated flexible plug means pumpable through said first tubing string by a fluid pressure therein, means detachably connecting said plug means to said extension hanger, means including a check valve for allowing fluid flow from the exterior of said extension hanger below said sealing means to the interior of said extension hanger, a well perforating gun, flexible means suspending said perforating gun from said extension hanger at a distance therebelow approximately equal to the distance from said zone to said first tubing string landing nipple whereby said perforator device is suspended adjacent said zone, a detonator housing member flexibly connected to said extension hanger for movement therewith, means providing fluid communication between the interiors of said detonator housing member and said extension hanger, a percussion cap in said detonator housing, hammer means within said detonator housing responsive to an extended duration of the presence of a predetermined fluid pressure therein to strike said percussion cap, means responsive to striking of said percussion cap for firing said perforating gun, and means including a relief valve openable by a fluid pressure in said first tubing string substantially greater than said predetermined pressure to provide fluid flow from the interior of said extension hanger to the exterior thereof below said sealing means.

17. Apparatus for perforating a desired zone of a well bore comprising a casing string lining said well bore, a tubing string extending down through said casing string with the lower end of said tubing string being above said zone, a landing nipple in said tubing string; an elongated flexible plug member in said tubing string and having an annular shoulder on each end thereof, a pair of collars surrounding said plug member with one each adjacent one of said shoulders, spring means biasing said collars towards said shoulders adjacent thereto with a predetermined force, an annular resilient seal member disposed against each of said shoulders and compressed thereagainst by said collars, the outer surfaces of said seal members being sealingly engaged with said tubing string by said spring means; a tubular extension hanger flexibly connected at one end thereof to one end of said plug member, said extension hanger having means thereon engaged with said landing nipple to prevent movement of said extension hanger through said landing nipple, packing means on said extension hanger sealing against said landing nipple; a detonator housing flexibly connected to the other end of said extension hanger, means providing fluid communication between the interiors of said detonator housing and said extension hanger, a detonator in said detonator housing, a fluid pressure actuated detonator actuator in the interior of said detonator housing responsive to the presence of an extended duration of a fluid pressure therein of a predetermined amount for actuating said detonator; a well perforating means flexibly connected to said detonator housing at a distance therefrom approximately equal to the distance from said zone to be perforated to said tubing string landing nipple; and means to operate said perforating means in response to actuation of said detonator.

18. Apparatus for perforating a desired zone of a well bore comprising a casing string lining said well bore, first and second tubing strings extending down through said casing string with the lower ends of said tubing strings being above said zone, packer means sealing said tubing strings to said casing string, a landing nipple in said first tubing string, said first tubing string being open from below the landing nipple therein to the interior of said casing string below said packer means and said second tubing string being also open to the interior of said casing string below said packer means; an elongated flexible plug member in said first tubing string and having an annular shoulder on each end thereof, a pair of collars surrounding said plug member with one each adjacent one of said shoulders, spring means biasing said collars towards said shoulders adjacent thereto with a predetermined force, an annular resilient seal member disposed against each of said shoulders and compressed thereagainst by said collars, the outer surfaces of said seal members being sealingly engaged with said tubing string by said spring means; a tubular extension hanger flexibly connected at one end thereof to one end of said plug member, said extension hanger having means thereon engaged with said landing nipple to prevent movement of said extension hanger through said landing nipple, packing means on said extension hanger sealing against said landing nipple; a detonator housing flexibly connected to the other end of said extension hanger, means providing fluid communication between the interiors of said detonator housing and said extension hanger, a detonator in said detonator housing, a fluid pressure actuated detonator actuator in the interior of said detonator housing responsive to the presence of an extended duration of a fluid pressure therein of a predetermined amount for actuating said detonator; a well perforating means flexibly connected to said detonator housing at a distance therefrom approximately equal to the distance from said zone to be perforated to said tubing string landing nipple; and means to operate said perforating means in response to actuation of said detonator.

19. Apparatus for perforating a desired zone of a well bore comprising: a casing string lining said well bore, a landing nipple in said casing string above said zone, first and second tubing strings extending down through said casing string with the lower ends of said tubing strings being above said zone and below said casing string landing nipple, packer means fixed to said first tubing string and landed in said casing string landing nipple to seal said tubing strings to said casing string, a landing nipple in said first tubing string, said first tubing string being open from below the landing nipple therein to the interior of said casing string below said packer means and said second tubing string being also open to the interior of said casing string below said packer means; an elongated flexible plug member in said first tubing string and having an annular shoulder on each end thereof, a pair of collars surrounding said plug member with one each adjacent one of said shoulders, spring means biasing said collars towards said shoulders adjacent thereto with a predetermined force, an annular resilient seal member disposed against each of said shoulders and compressed thereagainst by said collars, the outer surfaces of said seal members being sealingly engaged with said tubing string by said spring means; a tubular extension hanger flexibly connected at one end thereof to one end of said plug member, said extension hanger having means thereon engaged with said landing nipple to prevent movement of said extension hanger through said landing nipple, packing means on said extension hanger sealing against said landing nipple; a detonator housing flexibly connected to the other end of said extension hanger, means providing fluid communication between the interiors of said detonator housing and said extension hanger, a detonator in

said detonator housing, a fluid pressure actuated detonator actuator in the interior of said detonator housing responsive to the presence of an extended duration of a fluid pressure therein of a predetermined amount for actuating said detonator; a well perforating means flexibly connected to said detonator housing at a distance therefrom approximately equal to the distance from said zone to be perforated to said tubing string landing nipple; and means to operate said perforating means in response to actuation of said detonator.

20. Apparatus for perforating a desired zone of a well bore comprising a casing string lining said well bore, first and second tubing strings extending down through said casing string with the lower ends of said tubing strings being above said zone, packer means sealing said tubing strings to said casing string, a landing nipple in said first tubing string, said first tubing string being open from below the landing nipple therein to the interior of said casing string below said packer means and said second tubing string being also open to the interior of said casing string below said packer means; an elongated flexible plug member in said first tubing string having an annular shoulder on each end thereof, a pair of collars surrounding said plug member with one each adjacent one of said shoulders, spring means biasing said collars towards said shoulders adjacent thereto with a predetermined force, an annular resilient seal member disposed against each of said shoulders and compressed thereagainst by said collars, the outer surfaces of said seal members being sealingly engaged with said tubing string by said spring means; a tubular extension hanger flexibly and removably connected at one end thereof to one end of said plug member, said extension hanger having means thereon engageable with said landing nipple to lock said extension hanger against longitudinal movement relative to said landing nipple, packing means on said extension hanger to seal against said landing nipple, said extension hanger having first and second passages from the interior thereof to the exterior thereof below said sealing means, relief valve means in said first passage openable when the pressure within said extension hanger is sufficiently higher than the external pressure thereon for permitting fluid flow from the interior to the exterior thereof, check valve means in said second passage openable when the pressure exterior of said extension hanger is sufficiently greater than the pressure therein for permitting fluid flow from the exterior thereof to the interior thereof; a detonator housing flexibly connected to the other end of said extension hanger, means providing fluid communication between the interiors of said detonator housing and said extension hanger, a detonator in said detonator housing, a fluid pressure actuated detonator actuator in the interior of said detonator housing responsive to the presence of an extended duration of a fluid pressure therein of a predetermined amount for actuating said detonator; a well perforating means flexibly connected to said detonator housing at a distance therefrom approximately equal to the distance from said zone to be perforated to said tubing string landing nipple; and means to operate said perforating means in response to actuation of said detonator.

21. Apparatus for perforating a desired zone of a well bore comprising a casing string lining said well bore, a landing nipple in said casing string above said zone, first and second tubing strings extending down through said casing string with the lower ends of said tubing strings being above said zone and below said casing string landing nipple, packer means fixed to said first tubing string and landed in said casing string landing nipple to seal said tubing strings to said casing string, a landing nipple in said first tubing string, said first tubing string being open from below the landing nipple therein to the interior of said casing string below said packer means and said second tubing string being also open to the interior of said casing string below said packer means; an elongated flexible plug member in said first tubing string having an annular shoulder on each end thereof, a pair of collars surrounding said plug member with one each adjacent one of said shoulders, spring means biasing said collars towards said shoulders adjacent thereto with a predetermined force, an annular resilient seal member disposed against each of said shoulders and compressed thereagainst by said collars, the outer surfaces of said seal members being sealingly engaged with said tubing string by said spring means; a tubular extension hanger flexibly and removably connected at one end thereof to one end of said plug member, said extension hanger having means thereon engageable with said landing nipple to lock said extension hanger against longitudinal movement relative to said landing nipple, packing means on said extension hanger to seal against said landing nipple, said extension hanger having first and second passages from the interior thereof to the exterior thereof below said sealing means, relief valve means in said first pasage openable when the pressure within said extension hanger is sufficiently higher than the external pressure thereon for permitting fluid flow from the interior to the exterior thereof, check valve means in said second passage openable when the pressure exterior of said extension hanger is sufficiently greater than the pressure therein for permitting fluid flow from the exterior thereof to the interior thereof; a detonator housing flexibly connected to the other end of said extension hanger, means providing fluid communication between the interiors of said detonator housing and said extension hanger, a detonator in said detonator housing, a fluid pressure actuated detonator actuator in the interior of said detonator housing responsive to the presence of an extended duration of a fluid pressure therein of a predetermined amount for actuating said detonator; a well perforating means flexibly connected to said detonator housing at a distance therefrom approximately equal to the distance from said zone to be perforated to said tubing string landing nipple; and means to operate said perforating means in response to actuation of said detonator.

22. Apparatus for perforating oil wells and passable through a tubing string having a landing nipple made up therein, comprising: an elongated flexible plug member having an annular shoulder thereon, a collar surrounding said plug member adjacent said shoulder, spring means biasing said collar towards said shoulder with a predetermined force, an annular resilient seal member disposed against said shoulder and compressed thereagainst by said collar, the outer surface of said seal member being sealingly engageable with said tubing string by said spring means when said plug member is inserted in said tubing string; a vertically disposable tubular extension hanger flexibly connected at one end thereof to one end of said plug member, said extension hanger having means thereon engageable with said landing nipple to prevent longitudinal movement of said extension hanger through said landing nipple; a detonator housing connected to the other end of said extension hanger, means providing fluid communication between the interiors of said detonator housing and said extension hanger, a fluid pressure actuated detonator means in the interior of said detonator housing responsive to the presence of a fluid pressure therein of a predetermined amount for actuation thereof; a well perforating means flexibly connected to said detonator housing at a predetermined distance therefrom; and means to operate said perforating means in response to actuation of said detonator means.

23. Apparatus for perforating oil wells and passable through a tubing string having a landing nipple made up therein, comprising: an elongated flexible plug member, an annular resilient seal member disposed on each end of said plug member, the outer surfaces of said seal members being sealingly engageable with said tubing string when said plug member is inserted in said tubing string; a vertically disposable tubular extension hanger removably connected at one end thereof to one end of said

plug member, said extension hanger having means thereon engageable with said landing nipple to lock said extension hanger against longitudinal movement relative to said landing nipple, said extension hanger having first and second passages from the interior to the exterior thereof, relief valve means in said first passage openable when the pressure within said extension hanger is sufficiently higher than the external pressure thereon for permitting fluid flow from the interior to the exterior thereof, check valve means in said second passage openable when the pressure exterior of said extension hanger is sufficiently greater than the pressure therein for permitting fluid flow from the exterior thereof to the interior thereof; a detonator housing flexibly connected to the other end of said extension hanger, means providing fluid communication between the interiors of said detonator housing and said extension hanger, a fluid pressure actuated detonator means in the interior of said detonator housing responsive to the presence of a fluid pressure therein of a predetermined amount for actuation thereof; a well perforating means flexibly connected to said detonator housing at a predetermined distance therefrom; and means to operate said perforating means in response to actuation of said detonator means.

24. Apparatus for perforating oil wells and passable through a tubing string having a landing nipple made up therein, comprising: an elongated flexible plug member having an annular shoulder on each end thereof, a pair of collars surrounding said plug member with one each adjacent one of said shoulders, spring means biasing said collars towards said shoulders adjacent thereto with a predetermined force, an annular resilient seal member disposed against each of said shoulders and compressed thereagainst by said collars, the outer surfaces of said seal members being sealingly engageable with said tubing string by said spring means when said plug member is inserted in said tubing string; a vertically disposable tubular extension hanger flexibly connected at one end thereof to one end of said plug member, said extension hanger having means thereon engageable with said landing nipple to prevent longitudinal movement of said extension hanger through said landing nipple, packing means on said extension hanger to seal against said landing nipple; a detonator housing flexibly connected to the other end of said extension hanger, means providing fluid communiaction between the interiors of said detonator housing and said extension hanger, a detonator in said detonator housing, a fluid pressure actuated detonator actuator in the interior of said detonator housing responsive to the presence of an extended duration of a fluid pressure therein of a predetermined amount for actuating said detonator; a well perforating means flexibly connected to said detonator housing at a predetermined distance therefrom; and means to operate said perforating means in response to actuation of said detonator.

25. Apparatus for perperfating oil wells and passable through a tubing string having a landing nipple made up therein, comprising: an elongated flexible plug member having an annular shoulder on each end thereof, a pair of collars surrounding said plug member with one each adjacent one of said shoulders, spring means biasing said collars towards said shoulders adjacent thereto with a predetermined force, an annular resilient seal member disposed against each of said shoulders and compressed thereagainst by said collars, the outer surfaces of said seal members being sealingly engageable with said tubing string by said spring means when said plug member is inserted in said tubing string; a vertically disposable tubular extension hanger flexibly and removably connected at one end thereof to one end of said plug member, said extension hanger having means thereon engageable with said landing nipple to lock said extension hanger against longitudinal movement relative to said landing nipple, packing means on said extension hanger to seal against said landing nipple, said extension hanger having first and second passages from the interior thereof to the exterior thereof below said sealing means, relief valve means in said first passage openable when the pressure within said extension hanger is sufficiently higher than the external pressure thereon for permitting fluid flow from the interior to the exterior thereof, check valve means in said second passage openable when the pressure exterior of said extension hanger is sufficiently greater than the pressure therein for permitting fluid flow from the exterior thereof to the interior thereof; a detonator housing flexibly connected to the other end of said extension hanger, means providing fluid communication between the interiors of said detonator housing and said extension hanger, a detonator in said detonator housing, a fluid pressure actuated detonator actuator in the interior of said detonator housing responsive to the presence of an extended duration of a fluid pressure therein of a predetermined amount for actuating said detonator; a well perforating means flexibly connected to said detonator housing at a predetermined distance therefrom; and means to operate said perforating means in response to actuation of said detonator.

26. A detonator comprising an elongated tubular member having an axial bore therethrough and a restriction in said bore intermediate its ends, a percussion cap mounted in said housing member, a firing pin spaced from said percussion cap and mounted in said housing member bore for movement thereof into percussive engagement with said percussion cap, a piston member mounted in said housing member for axial movement in said bore and disposed on the side of said bore restriction away from said firing pin, a shaft member passing through said bore restriction and connected to said piston member, said shaft member having a portion of its length remote from said piston member of greater cross section than the portion of its length adjacent to said piston member, a firing pin engaging hammer carried by said shaft, said shaft and piston member being movable in said bore between a first position wherein said hammer is spaced from said firing pin and a second position wherein said hammer engages said firing pin and moves said pin into percussive engagement with said percussion cap, a quantity of hydraulic fluid filling said bore between said piston member and said bore restriction, and shear pin means connecting said piston member to said housing member when said piston member is in said first position.

27. A detonator comprising an elongated tubular member having an axial bore therethrough and a restriction in said bore intermediate its ends, a percussion cap mounted in said housing member, a firing pin spaced from said cap and mounted in said housing member bore for movement thereof into percussive engagement with said cap, a piston member mounted in said housing member for axial movement in said bore and disposed on the side of said bore restriction away from said firing pin, a shaft member passing through said bore restriction and connected to said piston member, said shaft member having a portion of its length remote from said piston member of greater cross section than the portion of its length adjacent to said piston member, means sealing between said bore restriction and said greater cross-section portion of said shaft member, a hammer carried by said shaft for engagement with said firing pin, said shaft and piston member being movable in said bore between a first position wherein said hammer is spaced from said firing pin and a second position wherein said hammer engages said firing pin and moves said pin into percussive engagement with said cap, a quantity of hydraulic fluid filling said bore between said piston member and said bore restriction, spring means resiliently biasing said piston member to said first position, and shear pin means connecting said piston member to said housing

member when said piston member is in said first position.

28. A detonator comprising an elongated tubular member having an axial bore therethrough and a restriction in said bore intermediate its ends, a percussion cap mounted in said housing member, a firing pin spaced from said cap and mounted in said housing member for movement thereof into percussive engagement with said cap, first and second spaced apart piston members mounted in said housing member for axial movement in said bore and disposed one on each side of said bore restriction, a shaft member passing through said bore restriction and connecting said piston members for unitary movement thereof, said shaft member having a portion of its length adjacent said first piston member of greater cross section than the remainder thereof, said shaft and piston members being movable in said bore between a first position wherein said first piston member is spaced from said firing pin and a second position wherein said first piston member engages said firing pin and moves said pin into percussive engagement with said cap, a quantity of hydraulic fluid filling said bore between said piston members, and shear pin means connecting said piston members to said housing member when said piston members are in said first position.

29. A detonator comprising an elongated tubular member having an axial bore therethrough and a restriction in said bore intermediate its ends, a percussion cap mounted in said housing member, a firing pin spaced from said cap and mounted in said housing member for movement into percussive engagement with said cap, first and second spaced apart piston members mounted in said housing member for axial movement in said bore and disposed one on each side of said bore restriction, a shaft member passing through said bore restriction and connecting said piston members for unitary movement thereof, said shaft member having a portion of its length adjacent said first piston member of greater cross section than the remainder thereof, said shaft and piston members being movable in said bore between a first position wherein said first piston member is spaced from said firing pin and a second position wherein said first piston member engages said firing pin and moves said pin into percussive engagement with said cap, a quantity of hydraulic fluid filling said bore between said piston members, shear pin means connecting said piston members to said housing member when said piston members are in said first position, and means forming an opening through said housing member into said bore to provide fluid communication between the exterior of said housing and the face of said first piston member engageable with said firing pin.

30. A detonator comprising an elongated tubular member having an axial bore therethrough and a restriction in said bore intermediate its ends, a percussion cap mounted in said housing member, a firing pin spaced from said cap and mounted in said housing member for movement thereof into percussive engagement with said cap, first and second spaced apart piston members mounted in said housing member for axial movement in said bore and disposed one on each side of said bore restriction, a shaft member passing through said bore restriction and connecting said piston members for unitary movement thereof, said shaft member having a portion of its length adjacent said first piston member of greater cross section than the remainder thereof, means sealing between said bore restriction and said greater cross-section portion of said shaft member, means forming a restricted passage from one side of said bore restriction to the other side thereof, said shaft and piston members being movable in said bore between a first position wherein said first piston member is spaced from said firing pin and a second position wherein said first piston member engages said firing pin and moves said pin into percussive engagement with said cap, a quantity of hydraulic fluid filling said bore between said piston members, spring means resiliently biasing said piston members to said first position, and shear pin means connecting said piston members to said housing member when said piston members are in said first position.

31. A detonator comprising an elongated tubular member having an axial bore therethrough and a restriction in said bore intermediate its ends, a percussion cap mounted in said housing member, a firing pin mounted in said housing member for movement between a first position wherein said pin engages said cap and a second position wherein said pin is spaced from said cap, first spring means resiliently biasing said pin to its second position, first and second spaced apart piston head members mounted in said housing member for axial movement in said bore and disposed one on each side of said bore restriction, a shaft member passing through said bore restriction and connecting said piston head members for unitary movement thereof, said shaft having a portion of its length adjacent said first piston head of greater cross section than the remainder thereof, means sealing between said bore restriction and said greater cross-section portion of said shaft, means forming a restricted bleed passage from one side of said bore restriction to the other side thereof, said shaft and piston heads being movable in said bore between a first position wherein said first piston head is spaced from said firing pin and a second position wherein said first piston head engages said firing pin and moves said firing pin against said percussion cap, a quantity of hydraulic fluid filling said bore between said piston heads, second spring means resiliently biasing said shaft to said first position, shear pin means connecting said shaft and piston head members to said housing member when said shaft and piston head members are in said first position, and means forming an opening through said housing member into said bore to provide fluid communication between the exterior of said housing and the face of said first piston head member engageable with said firing pin.

32. A method for perforating oil wells comprising installing a well casing string having a landing nipple made up therein in said well, logging the distance from a desired zone of perforation to said casing landing nipple, making up a tubing string having a tubing anchor and a landing nipple made up integrally therein at a predetermined spacing from one another, installing the tubing string in the casing string to land the tubing anchor in the casing landing nipple, connecting a well perforator to an extension hanger at a distance therefrom equal to the distance from said desired zone of perforation to said casing landing nipple plus the distance that said tubing landing nipple is above said tubing anchor, pumping said well perforator and extension hanger down through said tubing string by fluid pressure exerted in said tubing string from the upper end thereof, landing said extension hanger in said tubing landing nipple, and detonating said well perforator by said fluid pressure.

33. A method for perforating oil wells, comprising: installing a well casing string having a landing nipple made up therein in said well, logging the distance from a desired zone of perforation to said casing landing nipple, making up a tubing string having a tubing anchor and a landing nipple made up therein at a predetermined spacing from one another, installing the tubing string in the casing string to land the tubing anchor in the casing landing nipple, connecting a well perforator to an extension hanger at a distance therefrom equal to the distance from said desired zone of perforation to said casing landing nipple plus the distance that said tubing landing nipple is above said tubing anchor, pumping said well perforator and extension hanger down through said tubing string by fluid pressure exerted in said tubing string from the upper end thereof, landing said extension hanger in said tubing landing nipple, increasing the fluid pressure in said tubing string from the upper end thereof, detonating said well perforator after a predetermined interval while maintaining the increase of fluid pressure in said tubing string, pumping said extension hanger back up through said

tubing string by fluid pressure exerted in said tubing string from the lower end thereof.

References Cited in the file of this patent

UNITED STATES PATENTS

2,304,408 Holifield ..... Dec. 8, 1942
2,785,754 True ..... Mar. 19, 1957
2,805,718 Tausch ..... Sept. 10, 1957
2,810,440 Kenneday et al. ..... Oct. 22, 1957
2,810,442 Tausch ..... Oct. 22, 1957
2,859,697 Long ..... Nov. 11, 1958
2,879,848 Drummond ..... Mar. 31, 1959