Sept. 29, 1959 W. H. GRIFFIN 2,906,339

METHOD AND APPARATUS FOR COMPLETING WELLS

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Fig. 1

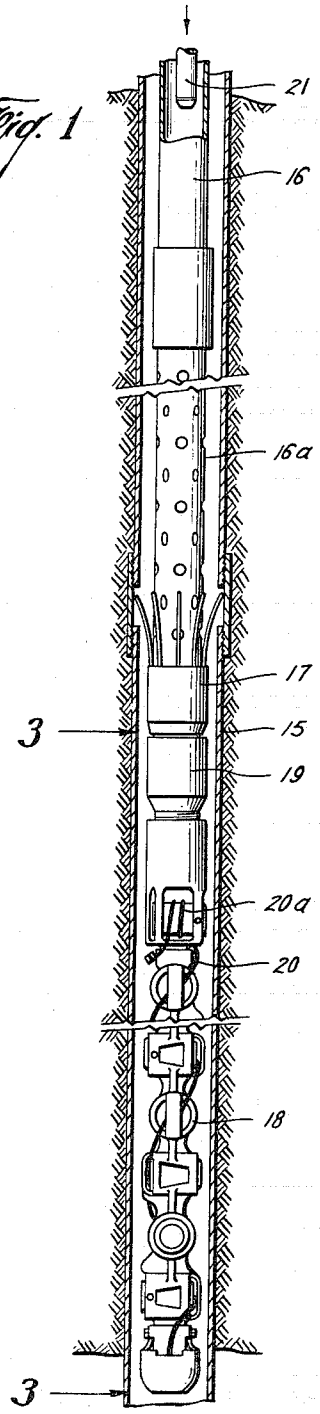
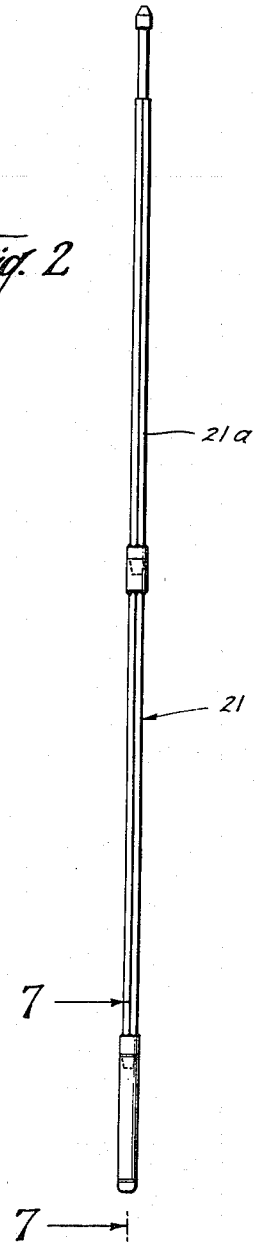


Fig. 2



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METHOD AND APPARATUS FOR COMPLETING WELLS

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Fig. 3

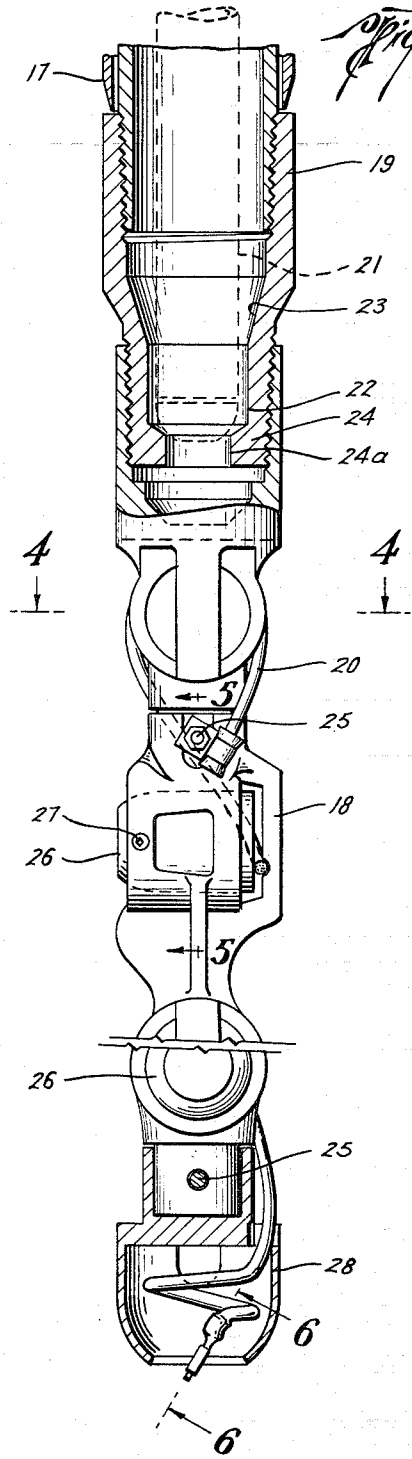


Fig. 4

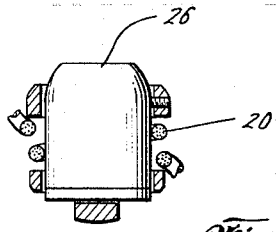


Fig. 5

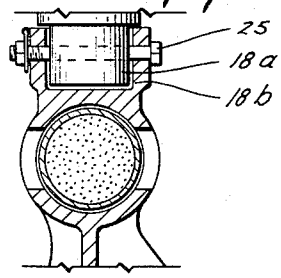
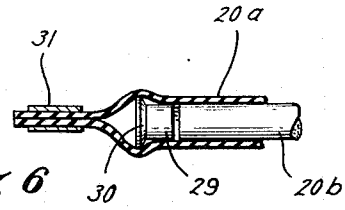


Fig. 6



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METHOD AND APPARATUS FOR COMPLETING WELLS

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Fig. 7

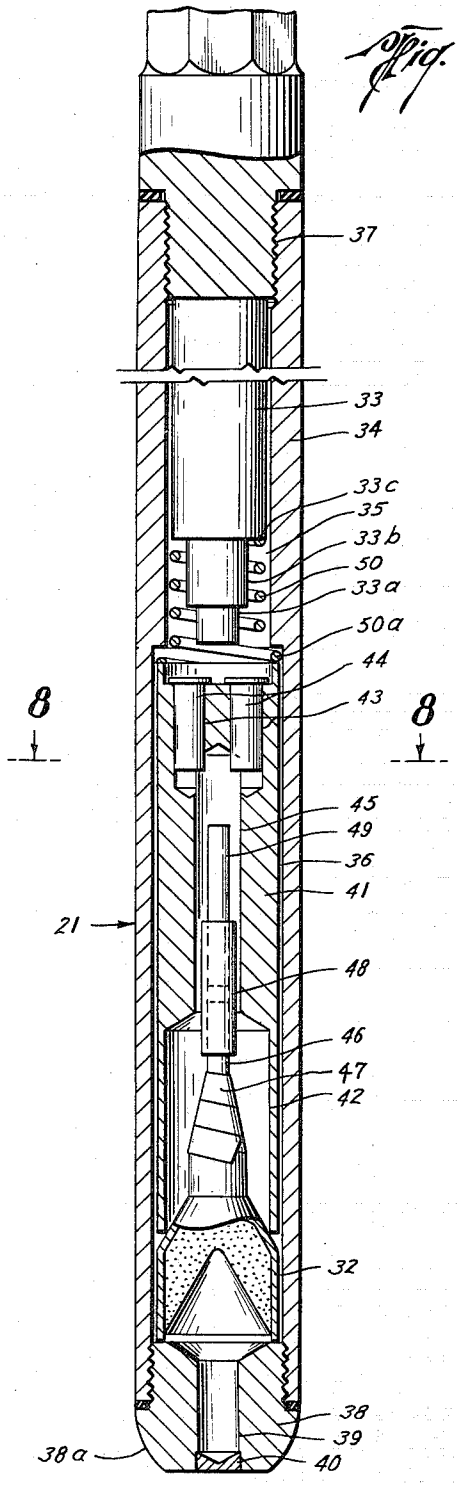


Fig. 8

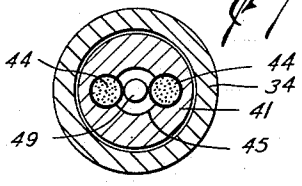


Fig. 9

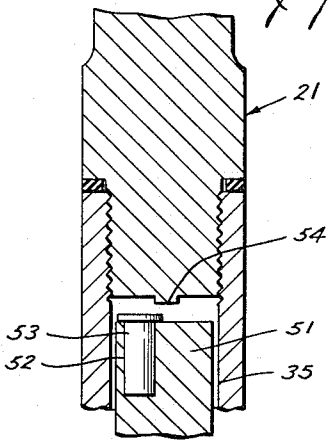
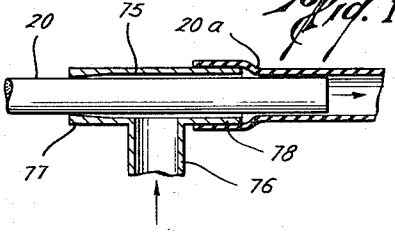


Fig. 10



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METHOD AND APPARATUS FOR COMPLETING WELLS

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Fig. 11

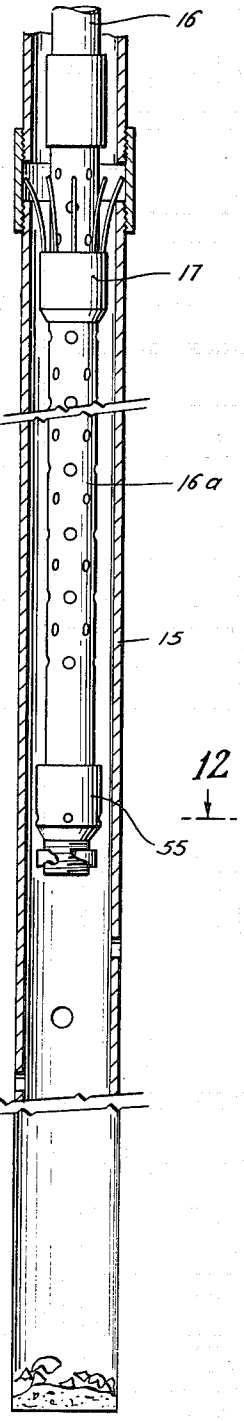


Fig. 13

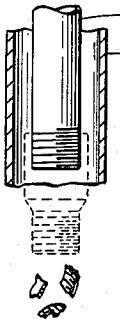


Fig. 12

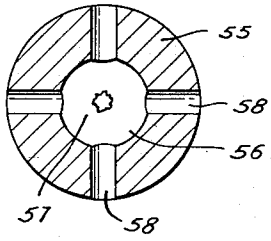
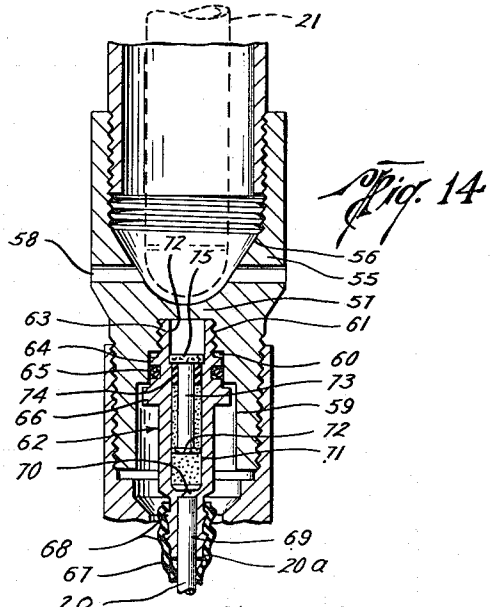


Fig. 14



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United States Patent Office 2,906,339 Patented Sept. 29, 1959

2,906,339

METHOD AND APPARATUS FOR COMPLETING WELLS

Wilber H. Griffin, Houston, Tex.

Application March 30, 1954, Serial No. 419,729

22 Claims. (Cl. 166—35)

This invention relates to the completion of wells. In one of its aspects it relates to a new means and method for firing a well perforator. In another of its aspects it relates to a detonator or actuator to be lowered or dropped into a well and fire through a stop to fire a perforator, pierce a closure, etc. In still another of its aspects it relates to a new method of well completion.

Heretofore, well perforating guns have included in one assembly both the perforating means and the apparatus for firing the gun. This arrangement gives rise to the problem of premature and unintentional firing of the gun both on the surface and in the hole. Various means have been provided to prevent accidental firing of the gun, but, notwithstanding the most elaborate precautions, unintentional firing of the guns heretofore used sometimes occurs.

Where the guns were mechanically fired they generally employed as a part of their firing mechanism conventional blank cartridges to set off their primer cords. These cartridges are loaded with a relatively unstable explosive such as fulminate of mercury. These unstable explosives, in addition to their instability, deteriorate in a short time under the elevated temperatures frequently encountered in present day deep wells, and when deteriorated sometimes fail to explode when desired. They also sometimes fire prematurely when subjected to elevated temperatures over an extended period of time. These characteristics do not normally present any particular problem when the perforating gun is run in on a wire line as the gun may be lowered into position in many instances in an hour or so. Where, however, it is desired to run the gun on the lower end of a string of production tubing for purposes which will hereinafter appear, the gun will be in the well upward of ten or twelve hours in many instances and some means needs to be provided to insure proper operation of the cartridges.

This invention contemplates the complete separation of the firing mechanism from the remainder of the gun until such time as the gun, less the firing mechanism, is in place in the well and it is desired to fire the gun. Thus, unintentional actuation of the gun by the firing mechanism is impossible. The firing mechanism will be in the well only a short time before the gun is fired and, therefore, the temperature in the well will not affect the firing mechanism. In the event misfire does occur, the firing mechanism can be retrieved with a wire line, reloaded, and run into the well again. Thus the gun, less the firing mechanism, can be run into the well without danger of having to pull the string to reload the firing mechanism.

When a well bore has been plugged and is ready for perforating it will usually be found that the bore is filled with a fluid such as drilling mud. The hydrostatic pressure exerted by this column of fluid at the formation may be greater than the pressure of the formation to be perforated. If the well is perforated with this fluid in place, the mud will tend to flow into the formation through the perforations. Thus, it is frequently desirable to replace this fluid before perforating with a lighter fluid which will exert a lesser pressure due to the hydrostatic head than the formation pressure. This procedure is highly desirable as the well will begin to flow as soon as it is perforated and the fluid in the well bore will not enter the formation in any appreciable amount (the firing of the gun is believed to carry some fluid into the perforations) and contamination of the formation will be held to a minimum. Where the formation pressure is not of a magnitude to permit the procedure outlined above, it is customary to first perforate the well and then induce flow by swabbing or the like to reduce pressure exerted by the hydrostatic head in the well. This, of course, permits contamination of the formation by fluid in the well bore, as for instance by mud plastering the perforations and the formation adjacent thereto, or where water is taken up by a bentonite formation causing the bentonite to swell, etc. Thus, it would be advantageous to have a method of well completion wherein a formation whose pressure is less than the hydrostatic pressure of fluid in the bore adjacent the formation when the well is perforated may be induced to flow immediately upon perforation of the formation. Such a method would also be useful where the formation pressure is of greater magnitude than the pressure exerted by a light column of liquid.

In many instances, it would be advantageous to have the lower end of the tubing full open when the last operation is complete to permit later work-over operations through a full open tubing. It would further be advantageous to be able to run a dry tubing into a well and after the tubing is run to open it to fluids in the well bore using a simple and inexpensive method.

It is an object of this invention to provide a method and apparatus for mechanically setting off an explosive charge in a well in which accidental firing of the explosive by the firing mechanism is impossible.

Another object is to provide a method and apparatus for mechanically setting off an explosive charge in a well in which the explosive is positioned in the well and the firing mechanism used to set off the explosive is only introduced into the well after the explosive is in place.

Another object is to provide a means and a method for mechanically firing a perforating gun in which accidental firing of the gun by the firing mechanism is impossible.

Another object is to provide a mechanically fired perforating gun which may be run into a well on the lower end of a production string without danger of misfiring due to deterioration of the firing mechanism by well temperatures.

Another object is to provide a perforating gun in which the gun, less the firing mechanism, is first positioned in the well, and then the firing mechanism is introduced into the well and fires the gun.

Another object is to provide a perforating gun adapted to be run on a production string of tubing, which upon firing falls to the bottom of the hole as debris, leaving the bore of the production string unobstructed to permit work-over operations through the production string.

Another object is to provide a go-devil actuator for perforating guns or like apparatus in which the go-devil fires a shaped charge into the gun or other apparatus to actuate same.

Another object is to provide a method and apparatus for completing wells in which the hydrostatic pressure exerted by the fluid in the well bore adjacent the formation to be produced is substantially reduced at the same time that the formation is perforated insuring immediate flow of the formation fluid into the well bore and preventing contamination of the formation by the fluid in the well bore.

Another object is to provide a method and apparatus

for completing wells in which the pressure of the formation to be produced is relatively low and in which the hydrostatic pressure exerted by the fluid in the well bore adjacent the formation to be produced is reduced at the instant of firing the perforating gun to a value immediate flow of the formation fluid into the well bore.

Another object is to provide a method and apparatus for permanently completing wells in which the production tubing is full open when the well is brought in.

Another object is to provide a simple and inexpensive means of removing a closure from the lower end of a string of tubing in a well.

Another object is to provide a new method of loading a primer cord in a flexible sheathing.

Other objects, advantages and features of this invention will be apparent to one skilled in the art upon a consideration of the written specification, the appended claims, and the attached drawings.

In the drawings wherein there is shown by way of example an illustrative embodiment of this invention, and wherein like reference numerals indicate like parts:

Fig. 1 is a view in vertical section through a well casing showing in vertical elevation a perforating gun embodying this invention positioned opposite the formation to be penetrated with a portion of the tubing cut away to show the go-devil actuator falling through the tubing;

Fig. 2 is a view in vertical elevation of a preferred form of go-devil actuator;

Fig. 3 is a view on an enlarged scale of the charge carrier and fitting thereabove taken along the line 3—3 of Fig. 1 with parts broken away to illustrate certain details, and showing the go-devil actuator of Fig. 2 in firing position in dotted lines;

Fig. 4 is a view along the line 4—4 of Fig. 3;

Fig. 5 is a view along the line 5—5 of Fig. 3;

Fig. 6 is a view along the line 6—6 of Fig. 3;

Fig. 7 is a view along the line 7—7 of Fig. 2;

Fig. 8 is a cross-sectional view through the go-devil actuator taken along the line 8—8 of Fig. 7;

Fig. 9 is a fragmentary view of a modified form of go-devil actuator;

Fig. 10 is a sectional view through the device utilized in loading primer cord in a flexible sheathing;

Fig. 11 is a view in vertical section through a well after the perforating gun has been fired with the tubing and a modified form of connector fitting shown in elevation, showing the casing perforated and the fragments of the charge carrier of the gun, which shattered when fired, on the bottom of the well;

Fig. 12 is a view along the line 12—12 of Fig. 11;

Fig. 13 is a fragmentary view of the lowermost length of a well tubing illustrating in dotted outline a brittle fitting for attaching the gun to the tubing which shattered and fell to the bottom of the well as debris when the gun was fired, leaving the production string open to permit work-over operations. This figure also illustrates the use of an imperforate string of tubing and fitting used when the gun is run on a dry string of tubing, wherein the fitting was shattered to open the tubing to well fluids at the same time that the gun was fired to reduce the pressure in the well bore adjacent the formation to be produced at the time of firing of the gun; and

Fig. 14 is a view in vertical section through a modified form of fitting for attaching the gun to the production string and illustrating the use of a booster as a part of the primer cord.

The perforating gun illustrated includes a more or less conventional carrier loaded with shaped charges. A primer cord extends from charge to charge and has a portion of its length positioned at the top of the carrier and in general axial alignment with the tubing from which the carrier is suspended. Such primer cord is a flexible cord-type explosive or detonator fuse, well known for this use, such as the well known "Primacord" manufactured by the Ensign-Bickford Company, of Simsbury, Connecticut. Usually it is a hollow fabric or plastic tube filled with a well known detonable explosive such as pentaerythritoltetranitrate. It may be fired by applying a detonating shock at any point of its length. A go-devil actuator, which may be dropped from the surface after the carrier is in place, carries the firing mechanism for the gun. The firing mechanism is inertia operated and is actuated by the go-devil landing upon the fitting by which the charge carrier is secured to the tubing. The firing mechanism sets off a shaped charge in the nose of the go-devil which in turn ignites the primer cord. While the actuator illustrated is a go-devil, it will be appreciated by those skilled in the art that the actuator might be run into the well and fired in other ways which will suggest themselves to persons skilled in the art. There may also be provided a booster for the primer cord which is positioned in the fitting in the line of fire of the shaped charge in the go-devil actuator so that the actuator upon firing will ignite the booster, which in turn insures that the primer cord will be fired.

Referring now to the drawings and in particular to Fig. 1, there is shown a casing 15 in a well bore and a tubing 16 in the casing. The lowermost section 16*a* of tubing 16 is perforated to provide ingress into the tubing while producing the well and to permit fluid in the well such as drilling mud to be removed by introducing water or oil or other fluids which would be less harmful to the formation. Replacing the well fluid with a lighter fluid will prevent the perforated formation from being partially or completely blocked or contaminated by the mud or other fluid due to a higher pressure fluid in the bore than the formation pressure of the formation penetrated which would cause well fluid to flow into the formation, and due to a deleterious fluid being carried into the formation by the bullet or force jet which penetrates the formation. Such U-tubing is preferably carried out with the perforate section of tubing 16*a* at or below the formation to be penetrated to remove the fluid from the well bore opposite such formation.

A collar locator 17 is slidably received about perforated sections 16*a* and assist in positioning the gun at the desired depth in the usual manner as will be readily understood by those skilled in the art.

The portion of the perforating gun which is run into the well on tubing 16 includes a charge carrier 18 secured to the lower end of tubing 16 by a fitting 19. The fitting 19 may be considered as a part of a perforating gun and provides a stop part for arresting downward movement of the go-devil shown in Fig. 2. The carrier 18 is loaded with shaped charges as a perforating means and is preferably of the type which shatters when the gun is fired, but it will be understood that this invention may be practiced with a hollow tube type carrier or with a gun employing bullets. A primer cord 20 which fires the shaped charges extends from charge to charge and has a portion of its length positioned at the top of the gun and in general axial alignment with the bore of tubing 16. Where the expendable type carrier 18 is employed a high speed primer cord 20 will be used as will be understood by those skilled in the art.

The go-devil 21 illustrated in Fig. 2 includes an explosive charge, preferably a downwardly firing shaped charge, in its nose. The go-devil may be made up with one or more weight sections 21*a* as illustrated to provide the necessary weight to rapidly carry it to the bottom of the hole.

The method of use of the perforating gun is as follows: The charge carrier 18 is run into the well on tubing 16 and located at the desired depth so as to be opposite the formation to be penetrated. The tubing may be landed, the well head connections completed and the heavy mud U-tubed out of the hole if desired. The go-devil 21 is then dropped through the tubing 16 until the explosive charge in its nose is fired by the go-devil striking the stop part in fitting 19 with sufficient force to operate the in-

ertia operated firing mechanism which sets off the charge, which in turn fires the gun by igniting the primer cord. While it is preferred to use a go-devil which is dropped from the surface, it will be understood that the go-devil might be lowered into the well on a wire line or that the charge might be lowered into the well and fired by other means.

At the time the well is perforated, all of the well head apparatus usually employed in flowing the well is in place. The go-devil will take several minutes to reach the bottom of the hole and all valves in the christmas tree may be in normal producing position when the well comes in to insure maximum control. Upon firing of the gun the carrier **18** will shatter and fall to the bottom of the hole in fragments as illustrated in Fig. 11. Formation fluids may then enter unobstructed through the perforations made by the gun and will enter the tubing through its perforate section. The go-devil may be fished from the tubing at a later time or may be left in the hole as desired.

It not infrequently occurs that the formation pressure of the formation to be penetrated will be less than the pressure within the cased well bore adjacent the formation due to the hydrostatic head of fluid in the well even though the well be filled with a light, unweighted fluid such as water. If the well is perforated while subjected to this hydrostatic head, the fluid in the well will enter and perhaps contaminate the formation. This may be avoided by running a perforating gun on an imperforate dry string of tubing closed at its lower end by an imperforate fitting, that is, a fitting which closes the end of the tubing to entry of fluid, and opening the tubing to well fluid adjacent the formation at the same instant that the formation is perforated. The method of accomplishing this is as follows: The perforating gun is run into the well on an imperforate dry string of tubing and positioned adjacent the formation to be perforated. A packer is then set between the casing and tubing and above the formation to pack off the formation from fluid in the annulus between the casing and tubing. The tubing is then opened to the fluid below the packer and simultaneously the formation is perforated. Preferably, this is accomplished by dropping a go-devil through the tubing and opening the tubing and firing the gun simultaneously by setting off a shaped charge in the nose of the go-devil when it lands on fitting **19**. The force jet from the shaped charge perforates the fitting to permit ingress of fluid into the tubing and at the same time ignites the primer cord. As the pressure within the tubing will be substantially atmospheric, the pressure in the well bore at the formation to be produced will be much less than the formation pressure upon opening of the tubing, and flow from the formation into the well bore will begin immediately upon perforation of the well and the formation will not be contaminated by fluid in the well bore.

The apparatus employed in the above set forth method might be the same as heretofore described with but slight modification. The tubing should, of course, be imperforate to exclude well fluid from its bore and fitting **19** would also be imperforate for the same reason. The shaped charge in the nose of the go-devil **21** would be fired adjacent the fitting **19** and the shaped charge would burn through the fitting **19** and fire the perforating gun. The hole burned through the fitting would permit entry of well fluid into the tubing at the same time that the gun is fired. If desired, a brittle fitting **19** may be employed which will shatter into fragments upon firing of go-devil **21** leaving a full open tubing.

If desired, tubing **16** might be partially filled with liquid to prevent putting too great a strain on the formation due to the sudden reduction of pressure in the well bore.

When the above method of well completion is employed, the fluid in the well cannot be replaced with lighter fluid as is possible when the perforating gun is run on a perforate section of tubing. Thus, if it is desired to replace the fluid in the well bore with some other fluid, this should be done before the perforating gun is run in.

It will also be understood that a closed string of tubing might be run at other times and for other purposes, and opened to well fluid with go-devil **21**, and such is contemplated by this invention.

Referring now to the details of the perforating gun illustrated and particularly to Fig. 3, the fitting **19** which secures the charge carrier to the string of tubing has a bore **22** in its end adapted to be secured to the production string **16**. A downwardly and inwardly sloping wall section **23** of the bore guides the go-devil **21**, shown in dotted outline, into a reduced diameter portion of bore **22**. The reduced bore section terminates in a stop **24** which arrests downward movement of the go-devil. Stop **24** is provided with a central bore **24***a* for the purpose of allowing fluid to circulate through fitting **19** while undesirable fluid is being dumped from the well. This will prevent any accumulation of solid particles in the fitting which might cushion the fall of the go-devil and prevent it from striking stop **24** with sufficient impact to operate the firing mechanism of the go-devil. This hole also acts more or less as a flame chamber and permits the shock wave and flame from the explosive in the nose of the go-devil to easily reach the portion of the primer cord **20** which is positioned therebelow. As will be illustrated in a modified form of fitting, it is not necessary to provide bore **24***a* in fitting **19** when a shaped charge is used as the charge will penetrate a stop such as **24** and ignite a primer cord therebelow.

The carrier **18** for the shaped charges is threadedly secured to the lower end of fitting **19** and provides a means for mounting the charges in the usual manner. Carrier **18** is a more or less skeleton frame made of a brittle material such as cast iron which will shatter upon firing of the gun and is made up in sections to permit the gun to have any desired number of shaped charges. Carrier **18** may be a hollow tube type carrier loaded with shaped charges which do not shatter if desired, but the expendable carrier is preferred.

The manner of securing the several sections of the charge carrier together is illustrated in Fig. 5. Each section of the charge carrier **18** is provided at one end with a male part **18***a* and at the other end with a female part **18***b*. The male and female parts of adjacent sections of the charge carrier are pinned together by a bolt and nut **25**. It will be noted that clearance is provided between parts **18***a* and **18***b* which will permit slight misalignment of the several sections of the carrier as it is run into the hole, if necessary.

Shaped charges **26** are locked in place in the charge receptacles of carrier **18** by set screws **27**. The charge receptacles of carrier **18** are spiraled about the carrier at 90° intervals to provide perforations spaced about and along the well bore as will be well understood by those skilled in the art.

A primer cord **20** extends from charge to charge and has a portion **20***a* of its length arranged in axial alignment with the bore of the tubing from which the carrier is suspended by wrapping the cord about the top shaped charge several times. This top shaped charge will be fired by the jet from the go-devil and thus will act as a booster and insure firing of the primer cord. One end of the primer cord is secured to the carrier by the uppermost bolt and nut **25** as indicated in Fig. 3 and the other end of the primer cord is inserted into a guide **28** on the lower end of the charge carrier. The primer cord should be protected from well fluid and for this purpose it may be encased within a flexible sheathing **20***a* such as synthetic rubber or the like.

In Fig. 6 there is illustrated a means for closing the open end of sheathing **20***a* to well fluids. The sheathing **20***a* is extended beyond the end of the primer cord a short distance. A rubber stopper **29** of substantially the same diameter as the inner diameter of sheathing **20***a*

provided with an outwardly extending annular ridge 30 of substantially greater diameter than the inner diameter of the sheathing is inserted into the end of the sheathing with its small diameter end foremost. The stopper is positioned in engagement with the end of core 20*b* so as to form substantially an extension thereof. The open end of sheathing 20*a* is inserted into a short tube of malleable metal 31 such as copper or the like which is then flattened or crimped to hold the stopper in place. The pressure of well fluid exerted against the sheathing 20*a* about the rubber stopper will prevent passage of well fluids between the stopper and the sheathing 20*a* and keep the primer cord dry.

Referring to Fig. 7, there is shown a preferred form of go-devil for firing the perforating gun. The explosive used is preferably a shaped charge 32 positioned in the nose of go-devil 21 and arranged to fire downwardly and axially of go-devil 21 when set off by the inertia operated hammer 33. The lower end of go-devil 21 is provided with a housing 34 having a bore 35 and a counter bore 36. The upper end of housing 34 is threadedly secured to the weight bars 21*a* of the go-devil by a threaded connection 37. The other end of the housing is closed by a plug 38. Nose plug 38 is rounded at 38*a* to prevent premature firing of the go-devil as it travels through the tubing. Plug 38 has an axial bore 39 through which the jet from the shaped charge passes when the shaped charge is fired. The bore is closed to exclude fluid by a transverse wall such as plug 40 which is burned out by the jet when the shaped charge is fired.

An elongate, tubular member 41 is positioned in bore 36. Tubular member 41 is provided at one end with an axial recess or bore 42 which partially receives shaped charge 32, and at its other end with a plurality of bores 43 which receive rim-firing blank cartridges 44. A flame chamber 45 leads from bore 43 to bore 42. A length of primer cord 46 extends from flame chamber 45 to the shaped charge 32 and has one end inserted into the rear of shaped charge 32 and held therein by several wraps of tape 47. A short section of tubing 48 is received over the other end of primer cord 46 and a blasting cap 49 is positioned in the section of flexible tubing with one end of the blasting cap directly adjacent the free end of primer cord 46. This blasting cap may be of any common variety employing a relatively unstable explosive such as fulminate of mercury. As illustrated in Fig. 7, the blasting cap will be positioned just below the ends of blank cartridges 44 and will be ignited by firing of blank cartridges 44. The blasting cap in turn will ignite the primer cord 46 which will set off shaped charge 32.

The inertia responsive firing mechanism includes a hammer 33 which is slidably mounted in slide chamber or bore 35 and spring-loaded away from member 41 by spring 50. Slide chamber 35 terminates at each end in abutment walls one of which is provided by tubular member 41 and the other by the weight member to which housing 34 is secured. Hammer 33 is provided with a reduced diameter portion 33*a* which serves as a firing pin to fire rim-fire cartridges 44 upon actuation of the hammer. Blank cartridges 44 are arranged equidistant from the central axis of housing 34 and a portion of the rim of each cartridge lies under firing pin 33*a*. An intermediate reduced diameter portion 33*b* between the firing pin 33*a* and the large diameter portion of the hammer provides a shoulder 33*c* against which spring 50 is seated. The intermediate diameter portion of the hammer 33*b* also provides a guide for spring 50. The other end 50*a* of spring 50 is seated against the adjacent end of member 41. When the actuator is assembled spring 50 urges hammer 33 away from rim-fire cartridges 44.

In operation the hammer 33 will move toward blank cartridges 44 against the force of spring 50 when the downward movement of go-devil 21 is abruptly arrested by the go-devil striking stop 24. When this occurs firing pin 33*a* will strike and fire rim-fire cartridges 44 which in turn will set off blasting cap 49. As noted above, the blasting cap 49 will fire primer cord 46 which in turn will fire shaped charge 32. The force jet and flame from shaped charge 32 will travel downwardly through bore 24*a* in fitting 19 and set off primer cord 20 to fire the perforating gun. There is but very slight clearance between housing 34 and member 41 and when shaped charge 32 is set off the blast will sufficiently distort the housing and member to retain member 41 in the go-devil even though plug 38 is severed from the go-devil.

In Fig. 9 there is shown a slightly modified form of the firing mechanism. Hammer 51 which corresponds to hammer 33 in the Fig. 7 embodiment is provided at its uppermost end with a cartridge receiving bore 52. A rim-fire cartridge 53 is received in bore 52 with a portion of its rim directly below a projection or firing pin 54. With this arrangement firing of the go-devil actuator will occur when hammer 51 is moved downwardly any appreciable distance even though it does not strike rim-fire cartridges 44 as upon the return of the hammer by spring 50 firing pin 54 will fire cartridge 53 which will move the hammer toward cartridges 44 with sufficient force to overcome the spring 50 and fire cartridges 44.

The explosives contained within blasting cap 49 and within blank cartridges 44 and 53 will not be affected by temperature conditions within the well as go-devil 21 will not be dropped into the well until the operator is ready to fire the perforator.

Referring now to Figs. 11, 12 and 14, there is shown a modified form of fitting for connecting the charge carrier to the well tubing. This form of fitting is preferred as it permits the use of a booster as a part of the primer cord whose explosive can be positively and permanently protected from well fluids without difficulty.

Fitting 55 secures the charge carrier to the string of tubing in the same manner as does fitting 19. The fitting is likewise provided with a tapering side wall 56 to guide the go-devil to the stop member 57 and cause the go-devil to be substantially centered in the bore of the fitting when it strikes stop 57. The fitting differs from fitting 19 in that the circulating port 24*a* has been replaced by a plurality of circulating ports 58 and in that the stop part 57 is imperforate. The lower portion of the fitting is provided with a bore 59, a reduced diameter bore 60, and a further reduced diameter and threaded bore 61. A booster 62 is received in these bores in the lower portion of the fitting. Booster 62 has a small diameter threaded portion 63 which is threadedly received in bore 61 and a slightly larger diameter portion 64 which is received in bore 60. Portion 64 of the booster is provided with an annular groove in which is positioned an O-ring 65 to prevent passage of fluids. A nut portion 66 on the booster has sufficient clearance with bore 59 to permit engagement of the nut by a wrench. The lower end of booster 62 is provided with a reduced diameter section about which the sheathing 20*a* of the primer cord 20 is received. A plurality of annular ribs 68 prevent the sheathing from being accidentally removed from the portion 67 of the booster and provide a fluid tight seal therebetween. This depending portion 67 of the booster is provided with a bore 69 in which there is received one end of primer cord 20. Bore 69 terminates in an imperforate web 70 which prevents the primer cord 20 from being pushed into the booster by well fluid.

The powder chamber of the booster is provided by a bore 71 which extends away from the web 70 and a counter bore 72 which extends the remaining length of the booster. The booster is loaded by pouring powdered explosive into its open end to provide a layer of explosive above web 70. A pasteboard washer 72 of substantially the same diameter as bore 71 is placed on the powder and supports a blasting cap 73. The blasting cap is of slightly lesser diameter than bore 71 and the annular space between the bore and blasting cap

is partially filled with powdered explosive. A rubber washer 74 is then inserted in this annular space above the explosive and a cardboard disk 75 seats against the shoulder between bores 71 and 72 and closes the powder chamber.

In using the modified form of fitting, go-devil 21 strikes stop 57 and in the manner explained above sets off shaped charge 32. Shaped charge 32 burns through the imperforate stop 57 and into booster 62 where it both ignites the loose powder and sets off blasting cap 73. These explosives destroy the thin web 70 and ignite primer cord 20 which in turn ignites the shaped charge in carrier 18. While the force jet of shaped charge 32 first burns through stop 57 and then ignites the primer cord, it will be understood that the speed of the jet is such that for practical purposes it may be considered that the go-devil simultaneously penetrates the stop and fires the primer cord. The subsequent firing of the shaped charge 26 also occurs so quickly they may be considered to fire simultaneously with the penetration of the stop. In Figs. 11 and 12 there is shown a fitting 55 which formed a part of a gun which has been fired. It will be noted in Fig. 12 that a substantially centrally located hole has been burned through web 57.

Fig. 11 also illustrates the manner in which collar locator 17 is utilized to locate the gun opposite a formation where the upper level of the formation does not commence immediately below a collar. As it will be well understood by those skilled in the art, the tubing is run into the well until the collar locator is below the collar which is desired to locate. Then the tubing is lifted up until the collar locator fingers engage the collar and impede further upward movement of the tubing. The tubing is then lowered the desired distance to locate the gun opposite the formation as illustrated in this figure.

Fig. 13 illustrates the use of a fitting fabricated from a brittle material such as cast iron to secure the carrier 18 to the tubing string 16. This form of fitting may advantageously be used when running a dry string of tubing to permit reducing the pressure in the well bore when the perforating gun is fired. This form of fitting is also preferred for permanent completion work as it shatters when the go-devil is fired and leaves the bottom of the string of tubing full open to permit work-over operations at a later date. The fitting may be imperforate or provided with wash holes depending upon the intended use. Whether the fitting is provided with wash holes or not, it is preferred that it either have a bore section in which the shaped charge of the go-devil is exploded or an internal explosive charge such as the booster in the downwardly facing bore of fitting 55. In either case, there will be a radially outwardly directed force wave from the explosive which will shatter the brittle fitting. The use of both expedients will provide a safety factor when such is desired. When a cast iron fitting is used the collar locator should be positioned further up the tubing 16 so that it will be above a joint in the tubing and be retained on the tubing.

It will be understood that either fitting 19 or 55 may be utilized without the circulating ports when it is desired to run the tubing into the hole dry. In such case, it may be desirable to load the tubing with a column of liquid such as water to prevent the tubing from collapsing due to the pressure encountered within the well. Of course, the heavy mud cannot be removed from the well when the tubing is run dry.

From the foregoing, it is believed that the method of assembly and of use of the perforating gun is apparent. The charge carrier 18 may be loaded in the shop or in the field. An entire gun may be loaded and assembled as a unit or the several sections of the carrier 18 may be loaded and taken into the field as sections where they are pinned together by bolts and nuts 25. In either event, the primer cord 20 is extended from charge to charge and has a portion of its length positioned directly below the stop part of the fitting either by wrapping the cord about the uppermost shaped charge as illustrated in Fig. 3, or by providing a booster as a part of the primer cord as shown in Fig. 14. The charge carrier 18 is made up on either fitting 19 or 55 or upon an imperforate form of fitting 19 or 55, as the case may be, which in turn is secured to the bottom of the string of production tubing to be run into the well. The tubing is run into the well in the usual manner and the carrier 18 positioned opposite the formation to be perforated, utilizing collar locator 17 in the usual manner. If a perforate section 16*a* of tubing is employed, the liquid in the well may be replaced by U-tubing if desired. At this time the packer between the tubing and casing is set, all well head connections completed, and the well made ready for normal production. As there is no heat sensitive explosive in the well at this time, the time element between location of the carrier in the well and firing of the gun is not critical, enabling the carrier to be run on the production tubing 16.

The go-devil is loaded either in the shop or in the field as desired. It will be noted that the housing 34 may be turned upside down and spring 50 dropped into the housing until its large diameter portion 50*a* rests upon a shoulder provided by bores 35 and 36. Member 41 with its associate rim-fire cartridges and shaped charge 32 may be inserted into bore 36 and nose plug 38 screwed into place to hold the assembly in place. If the housing is maintained in an upright manner so as to prevent dislodging blank cartridges 44, the thus assembled portion of the firing mechanism may be handled without danger of accidental firing as hammer 33 is not in place. If desired, the housing may be made up on the remainder of the go-devil to prevent accidental dropping of any objects into bore 35 which might possibly fire one of cartridges 44. When it is desired to drop the go-devil into the well, hammer 33 may be inserted in bore 35 and housing 34 made up on the remainder of the go-devil.

The go-devil may then be inserted through the bull plug in the top of the Christmas tree or its equivalent and dropped through the tubing until its fall is abruptly arrested by striking the stop part which will actuate the inertia operated hammer 33 causing it to fire blank cartridges 44, which in turn will set off shaped charge 32. The shaped charge 32 will in turn perforate the fitting and fire the primer cord setting off the charges in the perforating gun. While the go-devil is falling through the tubing, the bull plug is replaced in the Christmas tree.

Where the tubing is run with a perforate section 16*a*, the formation fluid will enter the well in the normal manner assuming the formation pressure to be greater than the pressure in the well bore at the formation. If this condition does not exist, the column of liquid in the well bore may be lowered by swabbing or the like to permit flow into the well bore.

Where the tubing is run dry, the pressure in the well bore adjacent the formation at the inistant of firing of the perforating gun will be considerably less than the formation pressure and formation fluids will immediately flow into the well bore.

In Fig. 10 there is shown diagrammatically an improved method of loading the primer cord 20 into the protective sheathing 20*a*. The primer cord is introduced into the sheathing 20*a* by utilizing a T-fitting 75 which has one of its ports 76 connected to a source of compressed air. Axial port 77 of T-fitting 75, through which the cord 20 is inserted, has an inner diameter which is substantially the same as the outer diameter of primer cord 20 to prevent substantial loss of pressure through this port. Sheathing 20*a* is first lubricated with soap stone or the like and one end is slipped over port 78 of T-fitting 75. Compressed air is then introduced through port 76 and the core of primer cord 20 introduced through port 77. Due to the substantial closing of port 77 by primer cord 20, the compressed air will flow out port 78

and through sheathing 20*a*. As the core of the primer cord is introduced into sheathing 20*a*, the compressed air will flow between the core and sheathing distending the flexible sheathing slightly and reducing friction between these two elements so that the core may be pushed through the sheathing 20*a* by loading it through port 77. It has been found that primer cords in excess of 100 feet in length may be loaded into flexible sheathing using this method.

From the above it will be seen that the objects set forth have been accomplished. There has been provided a method and apparatus for bringing in wells without contaminating the formation, even though the formation pressure be small. There has been provided a means of firing a perforating gun in which the firing mechanism is maintained separate from the remainder of the gun until it is desired to perforate the well. All heat sensitive powder is contained within the go-devil which remains in the well only a short time before the gun is fired and thus the well temperatures will not affect the perforating gun. When using the invention disclosed, the well head fittings may be finally completed for normal production of the well.

It will be appreciated that while this disclosure has been principally directed to a go-devil actuator which is dropped into the well, the actuator might, if desired, be lowered into the well and positioned directly over a portion of the primer cord and fired in other ways, as will be understood by those skilled in the art. While this would accomplish the desired results, the structure would be more complicated and would present hazards not present with the go-devil type of actuator.

From the foregoing it will be seen that this invention is one well adapted to attain all of the ends and objects hereinabove set forth, together with other advantages which are obvious and which are inherent to the method and apparatus.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims.

As many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

The invention having been described, what is claimed is:

1. The method of perforating a well comprising, lowering a loaded perforating gun, with a primer cord for firing it, into a well and positioning the gun at the desired depth, then lowering an explosive charge until the charge is positioned adjacent a portion of the primer cord which forms a part of the perforating gun and which when ignited will fire the gun, and setting off the explosive charge to ignite the primer cord.

2. A perforating gun for wells, comprising, a carrier having securing means adapted to be secured to the bottom of a string of tubing, a stop part adjacent the top of the carrier and positioned to block the passage of a body entering the carrier through said securing means, a primer cord, which when ignited will fire the perforating gun, extending along said carrier and having a portion of its length positioned directly below the stop part and a portion positioned to fire the gun when the cord is ignited, and an actuator comprising a body adapted to be lowered into the carrier through said securing means until the actuator reaches the stop part, a downwardly firing charge in the nose of said body and means for firing said charge, whereby the primer cord will be ignited by the charge when the actuator is fired while adjacent the stop part.

3. A perforating gun for wells, comprising, a carrier having securing means adapted to be secured to the bottom of a string of tubing, a stop part adjacent the top of the carrier and positioned to block the passage of a body entering the carrier through said securing means, a primer cord, which when ignited will fire the perforating gun, extending along said carrier and having a portion of its length positioned directly below the stop part and a portion positioned to fire the gun when the cord is ignited, a go-devil actuator comprising a body adapted to be dropped into the carrier through said securing means and strike the stop part, a downwardly firing charge in the nose of the body, and means responsive to the actuator striking the stop part for firing said charge to ignite the primer cord.

4. A perforating gun for wells, comprising, a carrier having securing means adapted to be secured to the bottom of a string of tubing, a stop part adjacent the top of the carrier and positioned to block the passage of a body entering the carrier through said securing means, a primer cord, which when ignited will fire the perforating gun, extending along said carrier and having a portion of its length positioned directly below the stop part and a portion positioned to fire the gun when the cord is ignited, and a go-devil actuator comprising a body adapted to be dropped into the carrier through said securing means and strike the stop part, a downwardly firing charge on the nose of said body, and an inertia operated firing mechanism operable to set off said charge when the actuator strikes the stop part, whereby the primer cord will be ignited when the actuator charge is fired by striking of the actuator against the stop part.

5. The gun of claim 4, wherein the securing means is a fitting for securing the gun to the string of tubing and the stop part is provided by said fitting.

6. The gun of claim 5, wherein the fitting is provided with an inwardly and downwardly tapered bore above the stop part which centers the actuator in the fitting to aim the blast from the charge.

7. The gun of claim 6, wherein the stop part is an imperforate, transverse member which closes said bore, said portion of the primer cord is positioned directly below the transverse member, and the charge is a shaped charge which when fired penetrates the transverse member and ignites the primer cord.

8. The gun of claim 6, wherein the stop part is an imperforate, transverse member which closes said bore, said portion of the primer cord is a booster positioned in the fitting directly below the transverse member, and the charge is a shaped charge which when fired penetrates the transverse member and ignites the booster.

9. A perforating gun for wells, comprising, a carrier having securing means adapted to be secured to the bottom of a string of tubing, a stop part adjacent the upper section of the carrier and positioned to block the passage of a body entering the carrier through said securing means, a primer cord, which when ignited will fire the perforating gun, extending along said carrier and having a portion of its length positioned directly below the stop part and a portion positioned to fire the gun when the cord is ignited, and an actuator comprising a body adapted to be dropped into the carrier through said securing means until its fall is abruptly arrested by the stop part, a downwardly directed explosive charge on said body, and a firing mechanism for said explosive charge including a spring-loaded, inertia-operated hammer, and a blank cartridge under the hammer which when fired will set off the explosive charge, whereby the primer cord will be ignited by said explosive charge when the firing mechanism is operated by the actuator striking the stop.

10. A fitting for securing to a string of tubing a perforating gun of the type employing an actuator which is separate from the remainder of the gun, comprising, a tubular body having a bore in one end, means on the body for connecting said end to a spring of tubing and the opposite end to a gun, said bore provided with an inwardly tapering section and an imperforate transverse

wall extending across said bore adjacent the small diameter portion of the tapering section.

11. The fitting of claim 10, wherein the fitting is brittle and will shatter into fragments when a shaped charge is set off in said bore.

12. A fitting for securing to a string of tubing a perforating gun of the type employing a go-devil actuator which fires upon impact, comprising, a tubular body having a bore in its end adapted to be secured to the string of tubing, said bore having an inwardly tapering section and a transverse wall extending across and closing the bore adjacent the small diameter portion of the tapering section to provide a centering means and a stop, respectively, for a go-devil, and a circulation port extending between the exterior of the body and said bore adjacent the wall.

13. An actuator for use in wells, comprising, a go-devil having an explosive charge in its nose positioned to fire outwardly of the go-devil, and an inertia operated firing mechanism including an inertia operated hammer carried by the actuator for setting off the charge.

14. An actuator for use in wells, comprising, a go-devil with an explosive charge in its nose, and a firing mechanism carried by the actuator for setting off the charge including an abutment wall, an inertia operated spring-loaded hammer above the wall and a blank cartridge and firing pin under the hammer and positioned to be engaged upon descent of the hammer to set off the charge.

15. A go-devil actuator, comprising, an elongate, tubular body having a slide chamber extending axially of the body and terminating in abutment walls, an explosive charge in the nose of the body, a blank cartridge in one abutment wall of said chamber adjacent the charge which when fired will set off the charge, a hammer slidable in said chamber to strike and fire the cartridge, and resilient means urging the hammer away from the cartridge.

16. A go-devil actuator, comprising, an elongate, tubular body having a slide chamber extending axially of the body and terminating in abutment walls, an explosive charge in the nose of the body, a blank cartridge in one abutment wall of said chamber adjacent the charge which when fired will set off the charge, a hammer slidable in said chamber to strike and fire the cartridge, a resilient means urging the hammer away from the cartridge and against the other abutment wall of the chamber, and a blank cartridge in one of the opposed surfaces of said hammer and other abutment wall, and a firing pin on the other such surface which when fired by the hammer moving away from said other wall and being returned by the spring will drive the hammer against said first-mentioned cartridge with sufficient force to fire said first-mentioned cartridge.

17. In combination, a fitting for closing the lower end of a string of tubing adapted to be run into a well, said fitting having a bore in its end adapted to be secured to the string of tubing and fabricated of a brittle material which will shatter when an explosive is set off in said bore, and an actuator comprising, an elongate, tubular body having an explosive charge in its nose and means for setting off said charge, said charge when exploded in said bore shattering the fitting into fragments.

18. In combination, a fitting for closing the lower end of a string of tubing adapted to be run into a well, said fitting having a bore in its end adapted to be secured to the string of tubing and fabricated of a brittle material which will shatter when an explosive is set off in said bore, a perforating gun depending from the fitting, and an actuator comprising, an elongate, tubular body having an explosive charge in its nose and means for setting off said charge, said charge when exploded in said bore simultaneously shattering the fitting into fragments and firing said perforating gun.

19. In combination, a fitting for closing the lower end of a string of tubing adapted to be run into a well, said fitting fabricated of a brittle material which will shatter when subjected to an explosion from within and having a bore in its end adapted to be secured to a string of tubing, an explosive charge positioned in said fitting, and an actuator comprising, an elongate, tubular body having an explosive in its nose, and means for setting off the charge in the actuator, said actuated charge in turn setting off the explosive charge in the fitting, said two explosive charges shattering the fitting into fragments.

20. The combination of claim 19 wherein the charge in the fitting is a part of a perforating gun which is fired by setting off said charge in the fitting.

21. The method of completing a well, comprising, running a perforating gun into a cased well bore on a string of tubing closed to entry of fluid from the well bore and positioning the gun opposite the formation to be produced, setting a packer between the casing and tubing above the formation to be produced to pack off the formation from fluid in the annular space between the casing and tubing and above the packer, and completing the well by simultaneously opening said tubing to fluid below the packer and firing the perforating gun, whereby when the formation to be produced is perforated the weight of the column of fluid in the annulus between the casing and tubing and above the packer will not be exerted on the formation.

22. In combination, a string of tubing adapted to be lowered into a well, a fitting closing the lower end of said string of tubing to entry of fluids, and a go-devil actuator for perforating said fitting and opening the string of tubing to fluids, and go-devil actuator comprising, an elongate, tubular body, an axially firing shaped charge in the nose of the body, and a firing mechanism carried by said body for setting off the shaped charge when the go-devil lands upon the fitting.

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Notice of Adverse Decision in Interference

In Interference No. 92,204 involving Patent No. 2,906,339, W. H. Griffin, Method and apparatus for completing wells, final judgment adverse to the patentee was rendered Feb. 12, 1963, as to claims 1 and 2.

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