US 20120103628A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2012/0103628 A1**

(43) **Pub. Date: May 3, 2012**

Stout

(54) **METHOD AND APPARATUS FOR SINGLE-TRIP TIME PROGRESSIVE WELLBORE TREATMENT**

(75) Inventor: **Gregg W. Stout**, Montgomery, TX (US)

(73) Assignee: **OILTOOL ENGINEERING SERVICES, INC.**, Willis, TX (US)

(21) Appl. No.: **13/285,109**

(22) Filed: **Oct. 31, 2011**

Related U.S. Application Data

(60) Provisional application No. 61/408,780, filed on Nov. 1, 2010.

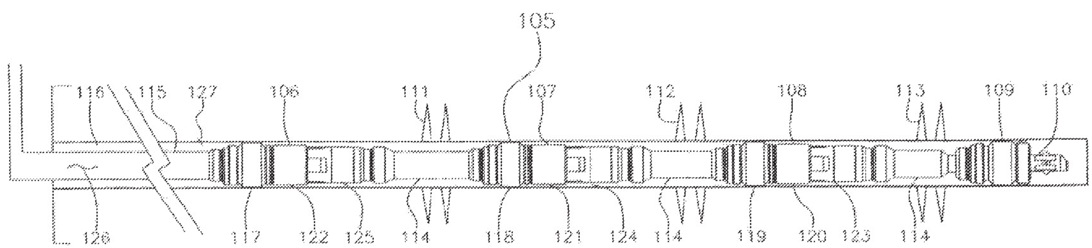
Publication Classification

(51) **Int. Cl.**
E21B 34/06 (2006.01)
E21B 34/00 (2006.01)

(52) **U.S. Cl.** **166/373**; 166/319

(57) **ABSTRACT**

A single trip multizone time progressive well treating method and apparatus that provides a means to progressively stimulate individual zones through a cased or open hole well bore. This system allows the operator to use pre-set timing devices to progressively treat each zone up the hole. At each zone the system automatically opens a sliding sleeve and closes a frangible flapper, at a pre-selected point in time. An adjustable preset timing device is installed in each zone to allow preplanned continual frac operations for all zones. The apparatus is present as a “Frac Module” that can consist of three major components, a packer, a timing pressure device, and a sliding sleeve/isolation device. A hydraulic packer may be removed or replaced with a swellable type packer.



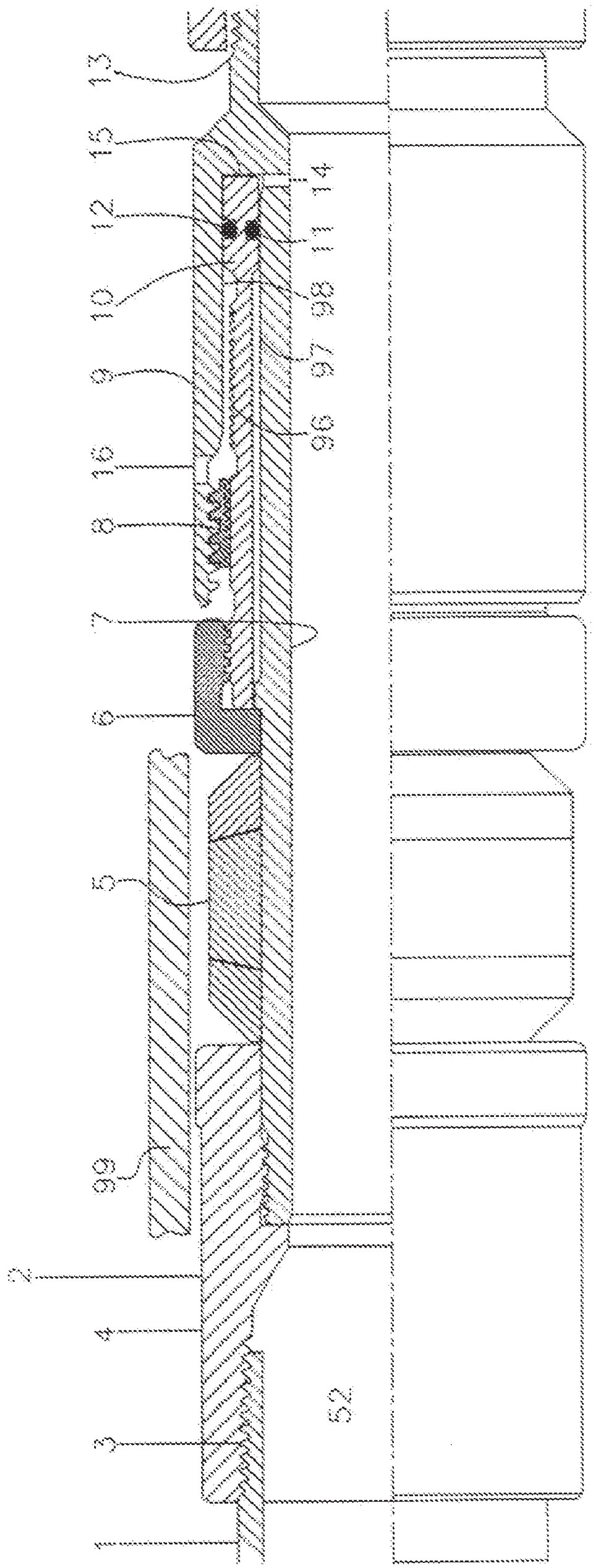


Fig. 1

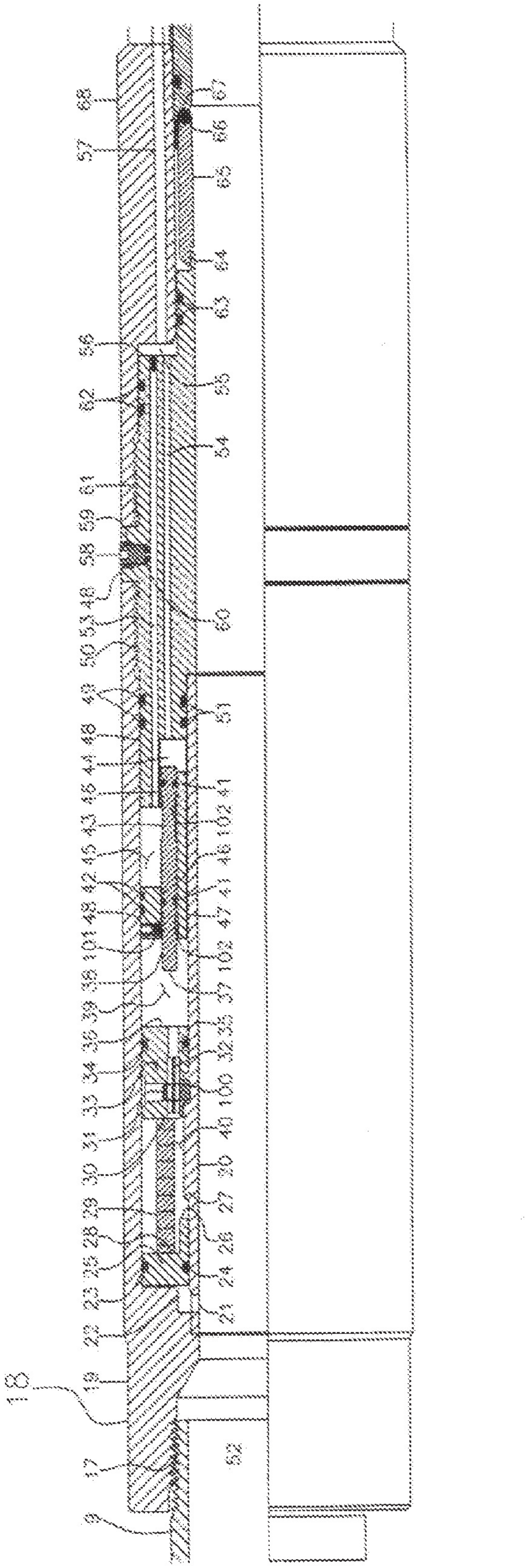


Fig. 2

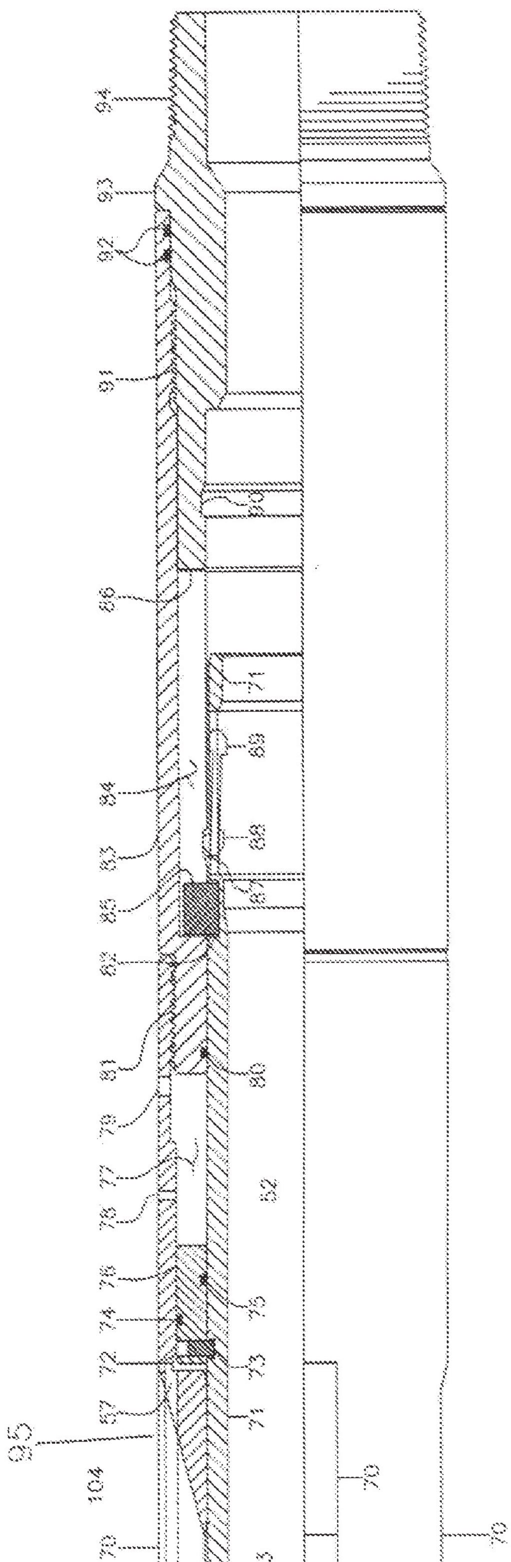

94
93
92
91
90
89
88
86
71
84
83
85
87
82
81
80
79
77
78
76
75
74
72
73
57
71
95
104
70
103
69
68
52
70
70

Fig. 3

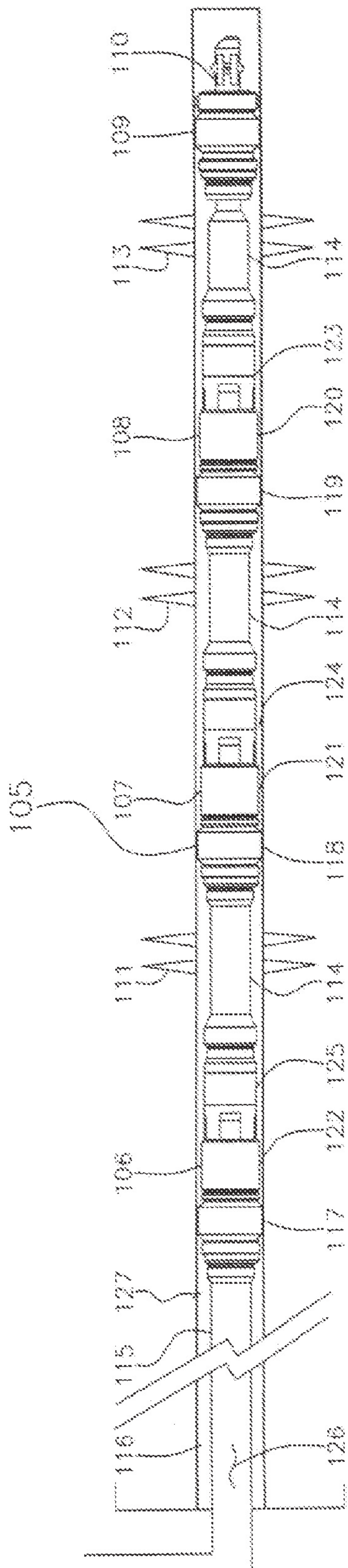

110
109
113
114
123
120
108
119
112
114
124
121
107
105
118
111
114
125
122
106
117
127
115
116
126

Fig. 4

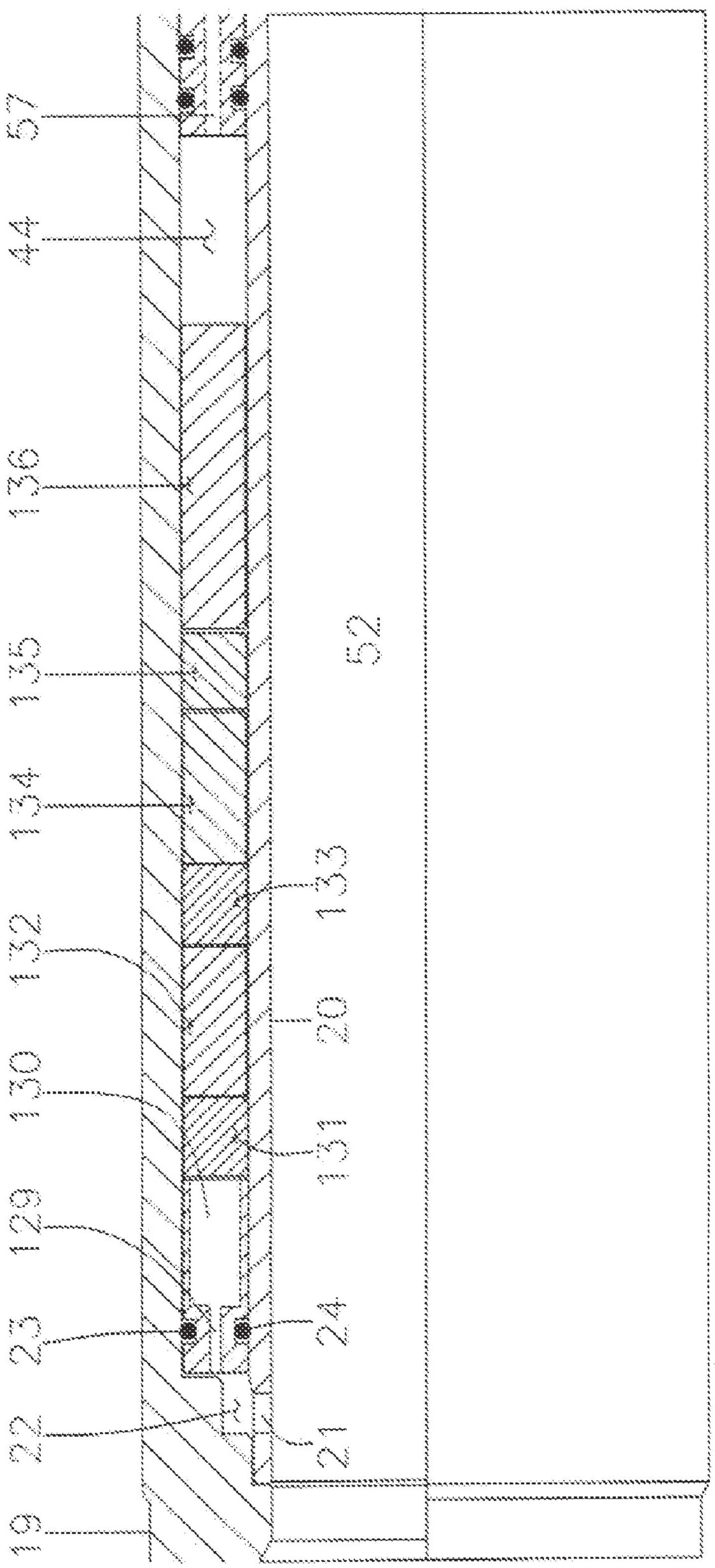


Fig. 5

METHOD AND APPARATUS FOR SINGLE-TRIP TIME PROGRESSIVE WELLBORE TREATMENT

[0001] This application claims priority to U.S. provisional application Ser. No. 61/408,780 filed on Nov. 1, 2010.

BACKGROUND OF INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to apparatus and methods for oil and gas wells to enhance the production of subterranean wells, either open hole, cased hole, or cemented in place and more particularly to improved multizone stimulation systems.

[0004] 2. Description of Related Art

[0005] Wells are drilled to a depth in order to intersect a series of formations or zones in order to produce hydrocarbons from beneath the earth. Some wells are drilled horizontally through a formation and it is desired to section the wellbore in order to achieve a better stimulation along the length of the horizontal wellbore. The drilled wells are cased and cemented to a planned depth or a portion of the well is left open hole.

[0006] Producing formations intersect with the well bore in order to create a flow path to the surface. Stimulation processes, such as fracing or acidizing are used to increase the flow of hydrocarbons through the formations. The formations may have reduced permeability due to mud and drilling damage or other formation characteristics. In order to increase the flow of hydrocarbons through the formations, it is desirable to treat the formations to increase flow area and permeability. This is done most effectively by setting either open-hole packers or cased-hole packers at intervals along the length of the wellbore. These packers isolate sections of the formations so that each section can be better treated for productivity. Between the packers is a frac port and in some cases a sliding sleeve or a casing that communicates with the formation or sometimes open hole. In order to direct a treatment fluid through a frac port and into the formation, a seat or valve may be placed above a sliding sleeve or below a frac port. A ball or plug may be dropped to land on the seat in order to direct fluid through the frac port and into the formation.

[0007] One method, furnished by PackersPlus, places a series of ball seats below the frac ports with each seat size accepting a different ball size. Smaller diameter seats are at the bottom of the completion and the seat size increases for each zone as you go up the well. For each seat size there is a ball size so the smallest ball is dropped first to clear all the larger seats until it reaches the appropriate seat. In cases where many zones are being treated, maybe as many as 20 zones, the seat diameters have to be very close. The balls that are dropped have less surface area to land on as the number of zones increase. With less seat surface to land on, the amount of pressure you can put on the ball, especially at elevated temperature, becomes less and less. This means you can't get adequate pressure to frac the zone because the ball is so weak, so the ball blows through the seat. Furthermore, the small ball seats reduce the I.D. of the production flow path which creates other problems. The small I.D. prevents re-entry of other downhole devices, i.e., plugs, running and pulling tools, shifting tools for sliding sleeves, perforating gun size (smaller guns, less penetration), and of course production rates. In order to remove the seats, a milling run is needed to mill out all the seats and any balls that remain in the well.

[0008] The size of the ball seats and related balls limits the number of zones that can be treated in a single trip. Furthermore, the balls have to be dropped from the surface for each zone and gravitated or pumped to the seats.

[0009] Another method, used by PackersPlus, U.S. Pat. No. 7,543,634 B2, places sleeves in the I.D. of the tubing string. These sleeves cover the frac ports and packers are placed above and below the frac ports. Varying sizes of balls or plugs are dropped on top of the sleeves and when pressuring down the tubing, the pressure acts on the ball and the ball forces the sleeve downward. Once again you have the restriction of the ball seats and theoretically, and most likely in practice, when the ball shifts the sleeve downward, the frac port opens and allows the force due to pressure diminish off before the sleeve is fully opened. If the ball and sleeve remain in the flow path, the flow path is restricted for the frac operation.

[0010] It would be advantageous to have a system that had no ball seats that restrict the I.D. of the tubing and to eliminate the need to spend the time and expense of milling out the ball seats, not to mention the debris created by the milling operation. Also, it would be beneficial to have a system that automatically fully opens each sliding sleeve and isolates the zone below, progressively up the well bore, before each zone is stimulated. Such a system allows stimulation of one zone at a time to achieve the maximum frac efficiency for each zone. In addition, it would be advantageous to be able to, in the future, isolate any zones by closing a sliding sleeve. For example, a single zone could be shut off if it began producing water or became a theft zone.

[0011] Furthermore, it would be greatly advantageous to eliminate the time and logistics required for dropping numerous balls into the well, one at a time, for each zone in the well to be treated. It would also be advantageous to have a multizone frac system that functioned automatically while all zones were being stimulated in order to minimize the time surface pumping equipment is setting idol between pumping zones.

[0012] Many wells are being stimulated at multiple zones through the well bore by use of composite plugs such as the "Halliburton Obsidian Frac Plug" or the "Owen Type 'A' Frac Plug". A composite plug is set near, or below, a zone and then the zone is treated. Another composite plug is set in the next upper zone and that zone is treated, and so on up the well bore until multiple plugs remain in the well. The composite plugs are then drilled out which can be time consuming and expensive. The shavings from the mill operation leave trash in the well and can also plug off flow chokes at the surface. It would be advantageous to have a system that eliminated the use and drilling out of composite or millable plugs. Of course, this approach would apply to new well completions where equipment, of the present invention, could be placed into the well prior to treating.

[0013] Other well completions, such as intelligent wells, are designed to operate downhole devices by use of control lines running from the surface to various downhole devices such as packers, sleeves, valves, etc. An example of this type of system can be found in Schlumberger U.S. Pat. No. 6,817,410 B2. This patent describes use of control lines and the various devices they operate. It is obvious the use of control lines can make the completion very complicated and expensive. The present invention allows operation of some types of downhole devices possible without the use of control lines.

For example, the present invention describes a timer/pressure device that could be placed both above and below a sliding sleeve, and days, months, or even years later, a sliding sleeve, or series of sliding sleeves, could be programmed to open or close.

[0014] There are other wells that sometimes require well intervention. A product called a Well Tractor, supplied by Welltec, is used to aid in shifting sliding sleeves opened or closed in long horizontal wells or highly deviated wells, sometimes in conjunction with wireline or coiled tubing operations. The present invention offers an alternate and more economical solution to functioning downhole devices in wells without well intervention.

BRIEF SUMMARY OF THE INVENTION

[0015] This invention provides an improved multizone stimulation system to improve the conductivity of the well formations with reduced rig time, no milling, and no control lines from the surface and, for some other applications, reduce well intervention. The equipment for all zones can be conveyed in single work string trip and frac units can stay on location one time to treat all zones.

[0016] This invention relates to an automatic progressive stimulation system where no control line or ball drop apparatus are needed. This system can also eliminate the need to set and mill out composite plugs in newly planned well completions. When single zone or multiple zone wells are to be completed with plans of stimulation and then producing, the equipment in the present invention can be utilized. This invention is comprised of three major components; a packer, a timer/pressure device, and a sliding sleeve/valve assembly. Although, in some cases, a packer may not be needed. The combination of these three components has been given the name "Frac Module".

[0017] I. The packer can be several types, such as those that set hydraulically by applying tubing pressure, those that are Swellable, or those that are Inflatable, to mention a few.

[0018] II. The timer/pressure device is a device that can be actuated by application of well pressure such as tubing pressure or annulus pressure. This pressure can act on a pressure sensitive device, which in turn triggers a timing device where the timing device can be set to any desired time, before it triggers a pressure generating device which is turn applies pressure to a downhole tool in order to activate the tool.

[0019] III. The sliding sleeve is a typical type sleeve that can open or close a port, or series of ports, that allow fluids or slurries to travel down the well conduit, through the ports, and communicate with the formation. For the present invention, the sliding sleeve would be of the piston type where pressure acts on a piston and in turn shifts the sleeve. A frangible flapper valve, or other type of valve, is positioned above the sliding sleeve and closes when the sliding sleeve shifts downward. The valve directs flow through the ports in the sliding sleeve and isolates the zone below.

[0020] A series of frac modules placed in the well act in unison, where all packers are set at once and all timers/pressure devices are triggered at once, with a single application of tubing pressure. Each timer in each zone can be set to a desired time so that, for example, the lowermost timer actuates a pressure generating device after one hour from the time when tubing pressure was initially applied. The pressure generating device creates pressure that communicates with a piston on the sliding sleeve to open the sliding sleeve and close the flapper valve. This first zone is treated through the sliding sleeve ports before the next upper sliding sleeve opens.

[0021] The next upper Frac Module timer is set for 2 hours, for example, from the time when initial tubing pressure was applied. At the end of the two hour time period, the timer actuates a pressure generating device to open its sliding sleeve so the zone can be treated. Timers in each zone can be set to the desired time to allow stimulating as many zones as required.

[0022] The timing devices can be set so that all zones can be nearly continuously treated in order to optimize the use of surface stimulation equipment. The timers are versatile enough where all the timers can be triggered at once. A portion of timers can be triggered at one selected pressure while others are triggered at different selected pressures, or sequences of applied pressures.

[0023] To those familiar with the art of well completions, it is obvious that the scope of this invention is not limited to just timer/pressure generating devices shifting sliding sleeves open or closed but can also be used to actuate any type or combination of a downhole tool device, or devices, in any timing sequence, such as perforating guns, valves, packers, etc. More than one timing/pressure device can be used to function a single type multiple times by setting the timers at different time spans.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

[0024] FIGS. **1**, **2**, and **3** placed end-to-end make up a schematic view of an embodiment of the present invention.

[0025] FIG. **4** is a schematic view of three Frac Modules assembled in tandem in a well completion.

[0026] FIG. **5** is a schematic showing a second embodiment of a timer/pressure device that can be used in the Frac Module.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0027] With reference to FIG. **1**, a schematic of an embodiment of the present invention shows a 90 degree lengthwise cross-section of the apparatus. This portion of the apparatus is a simplified view of a tubing pressure hydraulically set packer **2**, although packers such as swell and inflatable packers may be used. A packer maybe used that has a slip system added and a packer may be used that has a release device added.

[0028] Tubing string **1** has a connecting thread **3** that connects to top sub **4**. Top sub **4** threadably connects to packer mandrel **7**. Packing element **5** and gage ring **6** are positioned over Mandrel **7**. Ratchet ring **8** is located and threadably locked inside housing **9**. Piston **10** is threadably connected to gage ring **6** and ratchet ring **8** engages piston thread **96** as piston **10** strokes upward (left end of drawing). Seals **11** and **12** form a seal in bores **97** and **98** and between piston **10**. Tubing pressure **52** enters port **14** and acts across seals **11** and **12** to move piston **10** upward compressing packing element **5**. Fluid is displaced through port **16**. Ratchet ring **8** locks piston **10** so the packing element **5** stays compressed and sealed inside outer casing **99**. Housing **9** has pin thread **13** facing downward.

[0029] Referring to FIG. **2**, the timer/pressure assembly **18** is shown in a schematic. This schematic illustrates a totally mechanical timing/pressure device although other types of devices can be substituted such as a pressure sensitive pressure transducer interconnected to an electronic timer that initiates a pyrotechnics gas pressure generating device, for example. Such a device is shown in FIG. **5**.

[0030] Referring to the schematic, thread **17** of pin **13** connects to outer chamber **19**. Inner chamber **20** is trapped inside outer chamber **19** to form an annular space between the two chambers. Piston **25** has seals **23** and **24** that seal inside of inner and outer chambers **19** and **20**. Tubing pressure **52** enters port **21** and chamber **22** to act on piston **25**. The top end of compression spring **29** is shown in a near solid height condition where spring **29** makes solid contact with piston **25** at location **28**.

[0031] The bottom end of compression spring **29** makes solid contact with Orifice piston **33** at location **30**. Shear screws **31** shearably connect orifice piston **33** to inner chamber groove **100**. Piston **25** is allowed to stroke downward until face **26** contacts shoulder **27**.

[0032] A flow control device, such as a LEE Visco Jet **32** is located inside of orifice piston **33** so that fluid, such as silicone oil, located in chamber **39** can only pass thru Visco Jet **32** and into chamber **40**. Seals **34** and **35** seal orifice piston **33** on the inside walls of chamber **39**. Orifice piston **33** has face **36** that travels through chamber **39** to make contact with face **37** of pressure release rod **38**. Pressure chamber **48** is threadably connected to outer chamber **19** at thread **50**. Seals **42** and **49** isolate chamber **45** where chamber **45** is charged with a pressurized gas, such as nitrogen. Seals **41** on both ends of pressure release rod **38** also isolate chamber **45** to hold pressurized gas within the chamber. Chamber **39** communicates with chamber **44** through gap **47**.

[0033] Bores **46** inside of pressure chamber **48** are of near equal, or equal, diameter and seals **41** are of near, or equal, diameter so that pressure release rod **38** is in the pressure balanced condition when exposed to pressure from either chambers **39** or **45**. Pressure release rod **38** is held relative to chamber **48** by a low force spring loaded detent ball **101** to prevent pressure release rod **38** from moving until contacted by orifice piston face **36**.

[0034] Chamber **45** is charged with high pressure nitrogen gas through nitrogen charge valve **58** and longitudinal hole **53**. Hole **53** is sealed off at one end with plug **56** but is open to chamber **45** at the opposing end. Seals **59** and **60** seal the nitrogen charge valve **58** in order to prevent passage of gas out of chamber **45** and past the valve **58**.

[0035] A doughnut sleeve with internal o-rings and a sealed allen wrench, not shown, slides over nitrogen charge valve **58** to allow unscrewing Valve **58** to allow passage of gas through the doughnut and into chamber **45**. Once chamber **45** is at the desired pressure, the valve **58** is closed with the allen wrench to seal the chamber **45**.

[0036] Upper sleeve housing **68** is threadably attached to chamber **48** with thread **61** and sealed with seals **62**. Longitudinal hole **54** communicates with chamber **44**, not exposed to charged gas pressure at this time, and chamber **55** and hole **57**. Seals **63** isolate chamber **55** from pressure **52**. Seals **51** isolate pressure **52** from chambers **39** and **44**.

[0037] Pressure release rod **38** has recesses **43** and **102** so when shifted downward by spring force in spring **29** and face **36**, seal **41** leave seal bore **46** and pressurized gas can move from inside chamber **45** to chamber **55** and into hole **57**.

[0038] Frangible flapper valve **65** is mounted by axle **66** and is spring biased with spring **67** to rotate from the open position, shown, to the dosed position. Finger **64** temporarily holds the Flapper **65** in the open position. Axle **66** is positioned on the upstream portion of sleeve **71** and is carried by it.

[0039] Referring to FIG. **3**, this schematic shows ported sliding sleeve **95**. Upper sleeve housing **68** shows the continuation of hole **57** that communicates with chamber **72**. Sleeve piston **76** has seal **74** and **75** that isolate chambers **72** from **77**. Screw **73** connects piston **76** to sleeve **71**. Seal **69** isolates chamber **72** from pressure **52** and seal **80** isolates chamber **77** from pressure **52**. Seals **69** and **80** are of the same diameter so that sleeve **71** is pressure balanced, or near pressure balanced from pressure **52** so pressure **52** does tend to move sliding sleeve **71** up or down. Gas pressure in chamber **72** acts on piston **76** to move sliding sleeve **71** downward or to the open position.

[0040] Single or multiple ports **70** go through the wall of upper sleeve housing **68** and sleeve **71** and seals **69** and **80** prevent pressure or fluid from traveling from location **103**, through ports **70** and to location **104**, or vice versa. If pressure in chamber **72** is greater than pressure in chamber **77** and pressure acts on piston **76**, the piston **76** and sliding sleeve **71** will move downward toward chamber **77**. During this movement, fluid exits ports **78** and **79** to area **104**. When seal **74** passes port **78**, gas pressure above piston **76** and in chamber **72** passes through port **78** allowing the gas pressure to equalize.

[0041] Downward movement of sleeve **71** allows seal **69** to move past port **70** so that flow passage can occur from area **103** to area **104**. Also, when the sliding sleeve **71** moves downward, flapper **65** moves away from finger **64** and rotates around axle **66** allowing spring **67** to rotate flapper **65** to the closed position.

[0042] Collets **88** and **89** are common to sliding sleeves and come in different geometries. The collets lock the sliding sleeve **71** either in the up or down position in recesses **87** and **90**. Shifting tool profiles are added to the inside of the sliding sleeve **71** to use mechanical shifting tools run on wireline or tubing, to shift the sliding sleeve **71** closed or back open at some future time.

[0043] Sleeve housing **83** is threadably connected to upper sleeve housing **68** with thread **81**. A stop key **85** may be employed to engage shoulder **86** to stop the downward movement of sliding sleeve **72** as to not load collets **88** and **89** in compression. Stop key **85** sets in pocket **82** and can move downward in slot **84**.

[0044] Bottom sub **93** is threadably attached to sleeve housing **83** with thread **91** and is sealed with seals **92**. Pin thread **94** connects to a tubing spacer which in turn connects to another Frac Module or possibly a bottom locator seal assembly that stings into a sump packer.

[0045] Referencing FIG. **4**, this schematic shows a possible completion hookup **105** using three Frac Modules **106**, **107**, and **108** although many Frac Modules may be used. The well has casing **116** and below location **127** the well casing **116** can continue or the well can be open hole passing through zones **111**, **112**, and **113**. Packers **117**, **118**, and **119** can be tubing pressure hydraulic set packers for cased hole or swellable or tubing pressure set inflatable packers for either cased hole or open hole. Each zone can have a timer/pressure device **122**, **121**, and **120** and a ported sliding sleeve valve assembly **125**, **124**, and **123**. Each zone can be separated by tubing spacers **114** and tubing **115** runs to the surface or a hydraulic set production packer (not shown). A sump packer **109** can be set prior to running the completion string of frac modules. The bottom of the completion string can have a typical locator seal assembly **110** that stings into sump packer **109**. If it is desired not to run a sump packer **109**, the sump packer can be replaced with an additional tubing pressure set hydraulic packer that is set by dropping a ball on a seat below the packer. In either case, all tubing pressure set packers will set at the same time, if desired. Each zone is isolated with packers set above and below each zone and the sliding sleeves in the closed position.

[0046] Referring to FIG. **5**, this is a schematic of an embodiment of the present invention showing a second method of producing pressure to shift a sliding sleeve or other downhole device. Referencing FIG. **2**, this device can be put in the place of the device described in FIG. **2**.

[0047] Once again, there is an outer chamber **19**, an Inner chamber **20**, a port **21**, a chamber **22**, seals **23** and **24**, a chamber **44**, and a hole **57**. Pressure from area **52** enters port **21** into chamber **22** and into hole **129**. Pressure in hole **129** acts on a pressure sensitive device, such as a pressure transducer **130**. The pressure transducer triggers a switch **131** that starts an adjustable timer **132** that is set for a time frame, say 4 hours. The timer can be pre-set at the surface prior to running the tools into the well. The timer can be set for any time increment desired, for example from 1 minute to 100 hours, or longer. At the end of 4 hours it triggers a switch **133** to supply battery power **134** to an Igniter **135**, or initiator. The battery power can also run the timer or the timer can be purely mechanical. Power supplied to the igniter **135** triggers the igniter **135**, or initiator, to cause the material in the gas generator **136** to burn, react, or mix, and produce high pressure gas. The high pressure gas pressure increases in chamber **44**, travels through hole **57** to act on the piston **76**, shown in FIG. **3**. Pressure on the piston **76**, shifts the sliding sleeve **71** to the open, or down, position. Components **130**, **131**, **132**, **133**, **134**, **135**, and **136** can be moved, or substituted with other mechanisms, to different relative positions to achieve the same goal of producing gas pressure. These components can be in a single cartridge modular form, say one assembly, and can be miniaturized or improved by use of microelectronics. Also, more than one timer/pressure device can be used for redundancy and reliability purposes.

[0048] The device in FIG. **5**, and the device in FIG. **2**, illustrate that more than one technique can be used to create a timer/pressure device, and the present invention is not limited to one technique.

[0049] Furthermore, it is important to recognize that the timer/pressure device described in FIGS. **2** and **5** can be positioned relative to the sliding sleeve, FIG. **3**, either above or below the sliding sleeve, although if the timer/pressure device were positioned below the sliding sleeve, the hole **57** arrangement would be slightly more complicated when shifting the sleeve upward. A first timer/pressure device can be used to open the sleeve and a second timer/pressure device can be positioned below the sliding sleeve to close the sliding sleeve at a specified time in the future.

Description of Operation

[0050] With reference to the example in FIG. **4**, a typical completion is shown but many variations of this occur as known by those who are familiar with the variations that occur in configuring well completions.

[0051] A well has been drilled, cased, cemented, and perforated, although this system may be used in open hole completions with selection of the appropriate packers. Casing **116** is shown in this example with zones and perforations **111**, **112**, and **113** in the casing. The objective is to stimulate all of the zones **111**, **112**, and **113** in a single trip without well intervention. A sump packer **109** is properly located and set below the lowermost zone **113** although this packer may be substituted with a packer similar to packer **119** by landing a ball against a seat below where packer **109** is shown.

[0052] A "completion string" is run into the well consisting of a locator snap latch seal assembly **110**, tubing spacer **114**, frac module **108**, tubing spacer **114**, frac module **107**, tubing spacer **114**, frac module **106**, tubing spacer **114**, a service/production packer (not shown), and work string or production **115**. The length of tubing spacers **114** are made to position the frac modules **106**, **107**, and **108** between the producing zones **111**, **112**, and **113**.

[0053] The single trip completion string is landed in sump packer **109**. The location of sump Packer **109** is based on logs of the zones so that all equipment could be spaced out properly. Therefore, by locating the completion assembly on the sump packer **109**, all Frac Modules **106**, **107** and **108** will be properly positioned in the well. Snap latch seal assembly **110** can be used to verify position of the system before setting any of the packers **117**, **118**, and **119**. The locator snap latch seal assembly **110** seals in the sump packer **109** and will locate on the sump packer. The locator snap latch seal assembly **110** is designed to allow pulling of the work string **115** to get a load indication on the sump packer **109** and then snap back in and put set-down weight on the sump packer **109**. The above steps are common in the art of completing wells.

[0054] At this point in time the completion hardware, shown in FIG. **4**, is properly positioned around all the zones to be stimulated. All stimulation equipment has been positioned around the well at the surface and all frac lines have been assembled and pressure tested. A pumping company has done stimulation pre-planning for each zone and has all the necessary materials ready to pump, along with backup surface units. The Frac Module Timers were all set prior to running the system into the well but at this point in time, none of the timers have been actuated. The pumping company knows how long it will take to pump each zone and the timers were pre-set based on how long it will take to frac each zone. The timers were pre-set to allow extra time for any required surface operations during the overall process.

[0055] Now that the completion system is in the proper position in the well and all surface equipment has been nippled-up, the zones are ready to stimulate.

[0056] At this point all the sliding sleeves in each Frac Module are in the closed position. The operator may decide to do a low pressure system pressure test at this time before actuating any downhole devices. The entire system is pressured up, for example, to 500 psi and held for a period of time until there is proof of no leaks in the system.

[0057] At this point all surface equipment is running and the well is ready to stimulate. The first step is to set all of the packers, assuming that they are hydraulic tubing pressure set packers. If they are swellable packers, the operator will wait to begin operations until all of the Swellable packers have had time to swell.

[0058] Continuing and assuming the packers are tubing pressure set, the surface pump units begin applying tubing pressure **126** inside of work string **115** to packer setting ports **14**. All of the packers may be designed to begin setting at

1,500 psi and may not fully set until the tubing pressure reaches 3,500 psi, for example. This pressuring operation will take several minutes.

[0059] The same pressure **52** used to set the packers **117**, **118**, and **119**, also reaches the Frac Module timer pressure devices **122**, **121**, and **120**. In this case, all of the timers have been set to actuate close to the exact same time so when the tubing pressure reaches 1,500 psi, for example, all the devices **122**, **121**, and **120** start counting time. If the lowermost zone **113** is to be stimulated first, the timer in device **120** may have been set at 30 minutes, i.e., the amount of time before the first sliding sleeve **123** is opened and the flapper in the closed position. The timer is zone **112** may be been set for 2 hours and the timer in zone **111**, may have been set for 3 hours.

[0060] At this point in time, possibly 15 minutes after initial setting pressure was applied, all of the packers are set and all of the timers are running. It is now critical to begin pumping the job since the timer clocks are ticking. The first zone **113** will need to be fraced but the sliding sleeve **123** in Frac Module **108** must first open. The following paragraphs will explain how the Sliding sleeve **123** opens.

[0061] Referring to FIGS. **2** and **3**, pressure in area **52** enters port **21** and chamber **22** and acts on Piston **25**. Piston **25** and solid height compressed spring **29** pushes on orifice piston **33**. As piston **25** face **26** moves to shoulder **27**, shear screws **31** shear against groove **100**. The shear screws **31** may be set to shear at 1,500 psi applied to piston **25**. The force in spring **29** has sufficient force to move orifice piston **33** downward against the fluid in chamber **39**. The fluid in chamber **39** must be forced through Lee Visco Jet **32**. The Visco Jet has a Lohm rating that allows fluid to travel through the jet at a specified rate with a specified fluid, such as silicone oil, 200 cs. The specified flow rate of the fluid, the load of spring **29**, and the total volume of fluid in chamber **39**, controls the velocity and time in which the orifice piston moves toward rod **38**. The variables of spring load, Jet Lohm rating, fluid type, and total fluid volume can be adjusted ahead of time to achieve a 30 minute time dwell until face **36**, of orifice piston **33** contacts face **37** of the rod **38**.

[0062] The spring **29** has sufficient load and stroke to move rod **38** downward through charged nitrogen chamber **45**. When the rod undercuts **102** of rod **38** move downward and seals **41** move out of seal bores **46**, nitrogen gas is allowed to exit chamber **45** and enter chamber **44**, hole **54**, and hole **57**. The gas pressure is of sufficient magnitude so when it acts on sliding sleeve piston **76**, the sliding sleeve **71** is shifted downward to open up frac port **70**. Frac port **70** then allows fluid communication form area **103** to area **104**.

[0063] Simultaneously, flapper **65** is pulled downward away from finger **64**, and flapper **65** rotates around axle **66**, and is biased to the closed position by spring **67** to form a seal on top of sliding sleeve **71**. Once the sliding sleeve **71** is fully shifted downward, excess nitrogen gas is allowed to escape through port **78** in order to equalize pressure around the sliding sleeve **71**. This is important in case the sliding sleeve **71** needs to be shifted closed by mechanical shifting tools, at a later point in time after the well has been treated. The seals **23** and **24** on piston **25** provide a seal to prevent communication of fluid backward from port **78** to port **21** or vice versa. In this case, once the sliding sleeve **71** is fully shifted down, the collets **89** lock in groove **90** to hold the sliding sleeve in the open position. Likewise, when the sliding sleeve **71** is closed, collets **88** lock in groove **87** to hold the sliding sleeve **71** in the closed position.

[0064] At this point in time, the sliding sleeve **123** is shifted open and the flapper **65** is sealing the top of the sliding sleeve **71** so when pumping fluid from the surface of the well, fluid will not pass through the inside of sliding sleeve **71**, but will be blocked by the flapper **65** and directed through frac Port **70** and into formation **113**.

[0065] Formation **113** is treated by pumping fluid, or slurry, down work string **115**, through the upper Frac Modules **106** and **107** and out of ports **70** located in Frac Module **108**, and thru perforations **113** and into formation **113**. This operation has been planned by the pumping company to be complete before the 2 hour time period programmed in Frac Module **107**. Of course the 2 hour time period could have been reduced to minimize the time between treating zones.

[0066] After 2 hours from the original initiation point of setting the packers and starting the timers, the sliding sleeve **71** in Frac Module **107** opens and flapper **65** closes per the above described process, so zone **112** can now be treated.

[0067] This process continues for all zones that are in the completion and stimulation program for the well. As each zone is treated up the well, each Frac Module operates independently from the others, so failure of one to operate does not affect the operation of the others.

[0068] Once all zones are treated, the surface stimulation equipment can move off location. Flow from the formations can be used to attempt to clean up the well. The flow will open the flappers and allow fluid to move up hole.

[0069] It is also common practice to go back in the well, wash out excess proppant, if proppant was used, break the frangible flapper disc's, and close sliding sleeve **71** for zone isolation, if desired. The Sliding sleeves have profiles machined in the inside of the sleeves so that standard type mechanical shifting tools can be used to either open or close the ports **70**.

I claim:

1. A single trip well stimulation tool comprising:

a plurality of valve mechanisms;

a plurality of tubulars connected between the valve mechanisms; and

a plurality of time variable valve actuators.

whereby a plurality of repeating modules of a valve mechanism, a time variable valve actuator are formed in series.

2. A tool as claimed in claim **1** where each valve mechanism comprising a first port for allowing stimulation fluid to exit the valve mechanism and a valve member to block flow through the valve mechanism when the port is in an open position.

3. The tool as claimed in claim **2** wherein each valve mechanism includes a slidable sleeve which in one position covers the port and maintains the valve member in an open position and is moveable to a second position opening the port and causing the valve member to close.

4. The tool as claimed in claim **3** wherein the slidable sleeve is moved by fluid pressure acting on a piston connected to the slidable sleeve.

5. A tool as claims in claim **1** wherein the time variable valve actuators consist of a pressure transducer, a switch actuated by the pressure transducer, an adjustable timer activated by the switch, a second switch, a battery pack connected to the second switch, an igniter connected to the battery pack, a high pressure gas generator activated by the igniter and a piston having a surface exposed to high pressure gas when the gas generator is ignited.

6. A tool according to claim **1** wherein the time variable valve actuators include a first piston having a surface exposed to pressure within the tubulars, an orifice piston having a flow control device therein, a chamber filled with fluid, a pressure release rod, a second chamber charged with a pressurized gas, a second piston movable within a third chamber movable by the pressurized gas in the second chamber and a sleeve connected to the second piston.

7. A time variable valve actuator comprising:

a housing;

a first chamber having a fluid inlet, a first piston located in the first chamber;

a spring located in the first chamber and abutting the piston;

a orifice piston **33**;

a shoulder in the first chamber limiting movement of the first piston;

a second chamber filed with a fluid, the orifice piston positioned between the first and second chambers;

a pressure release rod having recesses on its outer surface;

a third chamber charged with a pressurized gas; and

the pressure release rod be movable within the third chamber to provide an outlet passageway from the third chamber through the recesses on the pressure release rod.

8. A method of stimulating a well which includes dividing the well into a plurality of discrete zones to be stimulated comprising:

placing into the well in a single trip a tool string comprising a plurality of valve mechanisms, time variable valve actuators and tubulars arranged to form a plurality of stimulation modules each comprising a section of tubing, a valve mechanism, and a time variable valve actuator; each time variable valve actuator including an activating mechanism for a timer mechanism;

presetting the timer mechanism to actuate the valves at varying time intervals;

activating the activating mechanisms for the timer mechanisms; and

pumping the stimulating fluid through the tubulars.

9. The method of claim **8** wherein the stimulation fluid is pumped continuously until all the zones have been treated.

10. The method of claim **8** wherein the timing mechanism for the valve actuators is activated by the pressure of the well fluid or stimulation fluid.

11. The method of claim **8** including the step of positioning a locator seal assembly and a sump packer at the downhole end of the tool string.

12. The method of claim **8** wherein each valve mechanism comprising a first port for allowing stimulation fluid to exit the valve mechanism and a valve member to block flow through the valve mechanism when the port is in an open position.

13. The method of claim **12** wherein each valve mechanism includes a slidable sleeve which in one position covers the port and maintains the valve member in an open position and is moveable to a second position opening the port and causing the valve member to close.

14. The method of claim **8** further comprising:

providing a plurality of packers in the tool string and setting the packers within the well.

15. The tool of claim **1** further including a timer actuator for each of the time variable valve actuators.

16. The tool of claim **15** wherein the timer actuator is activated by fluid pressure.

17. A tool as claimed in claim **1** further including a plurality of packers connected between the tubulars and the valve mechanisms.

18. A well system apparatus comprising a plurality of downhole tools actuated by a plurality of time variable actuators where the downhole tools are operated in a time sequence.

19. Apparatus for use in a well comprising:

a time variable actuator for actuating a tool;

a tool connected to the actuator; and

an activating mechanism for the time variable actuator.

* * * * *