

Aug. 16, 1966

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3,266,575

SETTING TOOL DEVICES HAVING A MULTI-STAGE POWER CHARGE

Filed July 1, 1963

3 Sheets-Sheet 1

Fig. 1

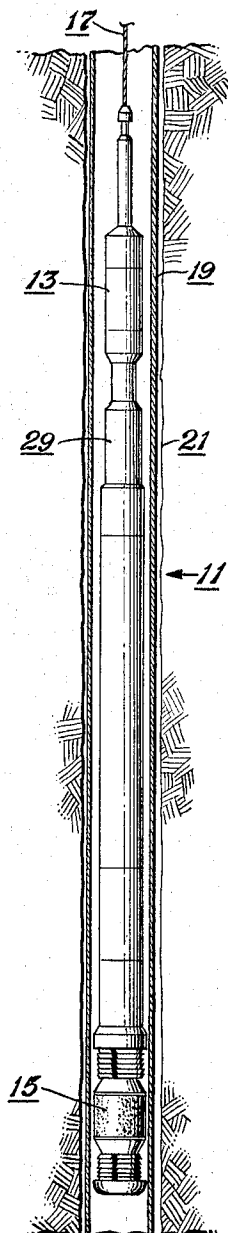


Fig. 2

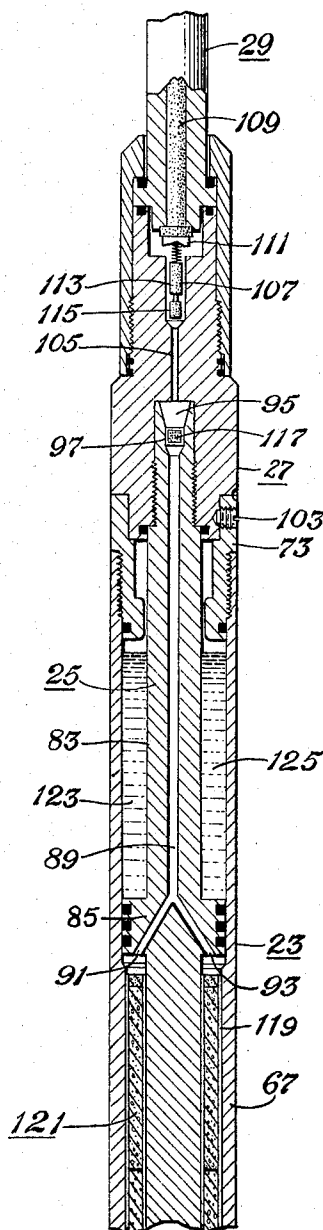
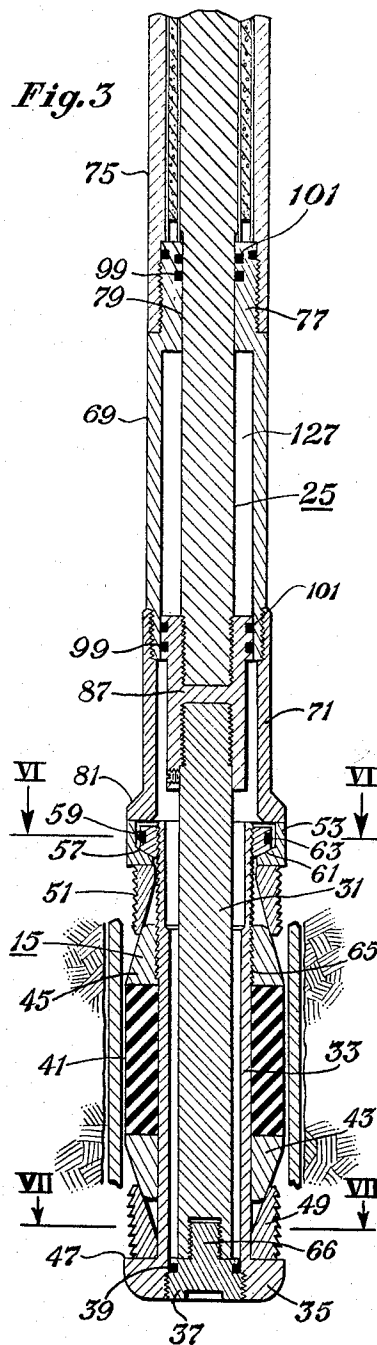


Fig. 3



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Fig. 4

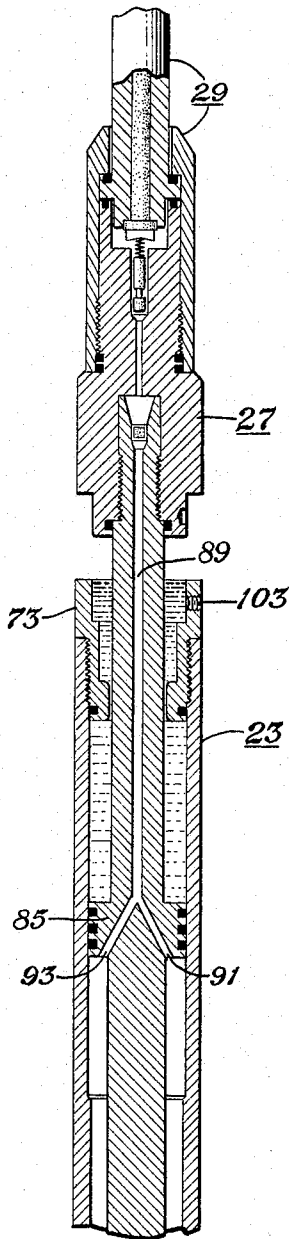


Fig. 5

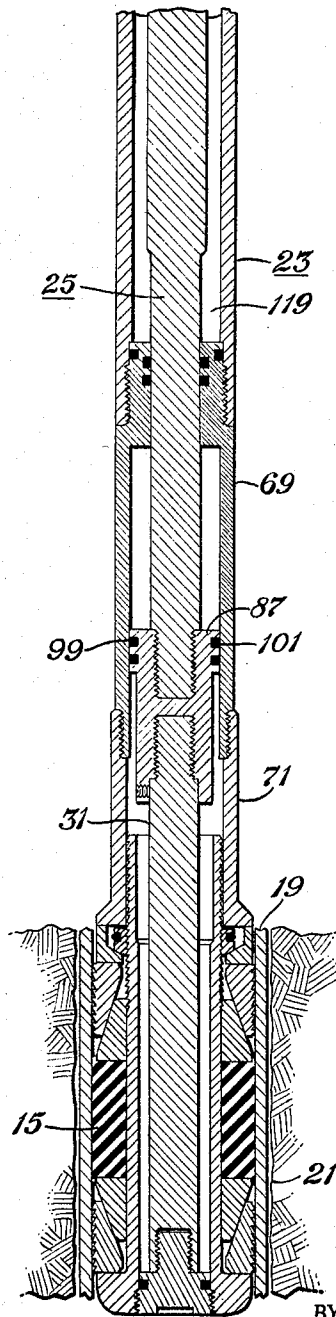


Fig. 6

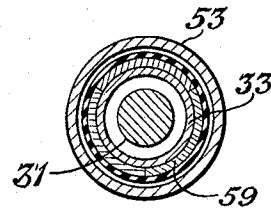
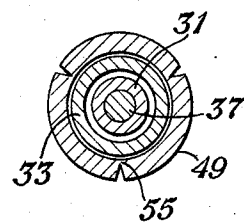


Fig. 7



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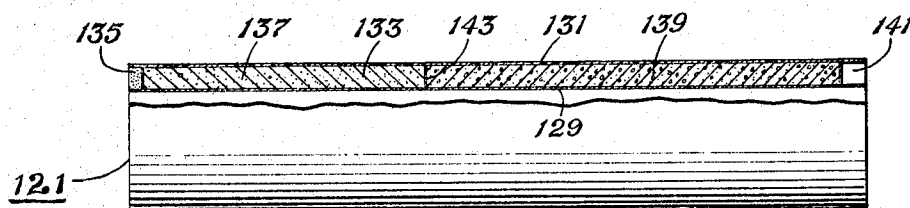


Fig. 8

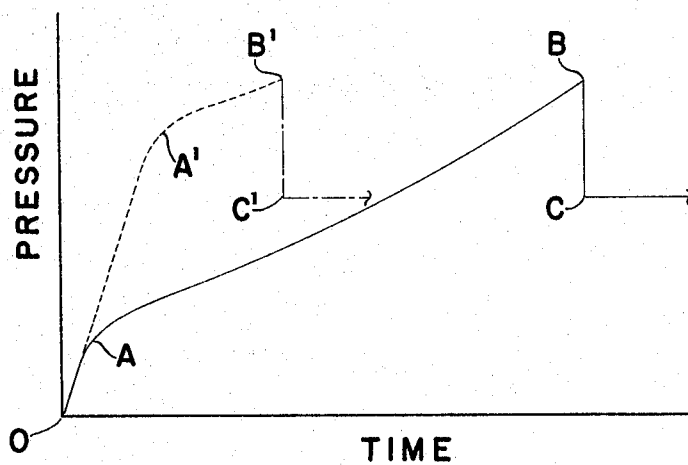


Fig. 9

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SETTING TOOL DEVICES HAVING A MULTI-STAGE POWER CHARGE

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5 Claims. (Cl. 166—63)

My invention relates to subsurface well apparatus and more particularly to setting tool devices for setting a bridge plug or sealing device in the casing or liner string of a well, or in the bore hole itself.

During the drilling of a well, it frequently happens that more than one zone of expected production may be found. In order to be able to produce from each probable zone, as well as for many other purposes, it is common practice at the present time to set one or more sealing devices in the casing or lower string, and sometimes in the bore hole itself. The usual procedure to make such a seal is to run in the hole, by means of a wire line, a setting tool device having a bridge plug attached to its lower end. When the setting tool reaches a predetermined depth, it is actuated by remote control to set the bridge plug.

The most commonly used setting tools are of the wire line type wherein the setting power is provided by the burning of a pressure generating charge within the tool. This pressure generating charge of course plays a vital part in the successful operation of the setting tool. Such pressure generating charges of the prior art of which I am aware have not proven to be ideal.

An object of the present invention is to provide an improved pressure generating charge for use in a wire line type setting tool.

Another object of the invention is to provide an improved setting tool device incorporating an improved multi-stage activating power charge.

These and other objects are effected by my invention as will be apparent from the accompanying drawings forming a part of this specification, in which:

FIG. 1 is a schematic elevational view of a wire line setting tool of a type which may utilize the invention, the tool being shown within a cased well bore;

FIG. 2 is a fragmentary longitudinal sectional view of the upper part of the device of FIG. 1 showing it in one operative position;

FIG. 3 is a longitudinal sectional view of the lower part of the device of FIG. 1 showing it in the same operative position as FIG. 2;

FIG. 4 is a fragmentary longitudinal sectional view corresponding to FIG. 2, but showing the device in another operative position;

FIG. 5 is a longitudinal sectional view corresponding to FIG. 3, but showing the device in the same operative position as FIG. 4;

FIG. 6 is a cross sectional view taken along line 6—6 of FIG. 3;

FIG. 7 is a cross sectional view taken along line 7—7 of FIG. 3;

FIG. 8 is a schematic view, partly in section of a typical multi-stage power charge in accordance with the invention; and

FIG. 9 is a graph generally indicating pressures developed by typical multi-stage power charges (ordinate) against time (abscissa).

Referring to the drawings, FIG. 1 illustrates a setting tool device 11 (sometimes hereinafter referred to as the

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device 11), a collar locator and cable head assembly 13, and a bridge plug 15, all of which are suspended from a wire line 17 in a section of casing 19 in a well bore 21, all of which components are shown and described in my co-pending application, Serial No. 185,040, U.S. Pat. No. 3,186,485, filed April 4, 1962, to which reference may be made.

Generally speaking, the device 11, as may be noticed by referring to FIGS. 2 and 3, includes a hollow cylindrical main body portion 23, an internal piston and piston rod assembly 25, a firing head 27 surmounted by a quick change assembly 29, and an adapter rod 31.

The bridge plug 15, as illustrated in FIGS. 3 and 5, is a type well known to those skilled in the art. Essentially, it includes a tubular portion 33 having an enlarged head 35 at its lower end and a plug portion 37 screwed into a threaded central passage in the head portion 35. An O-ring gasket 39 is located between the plug portion 37 and the tubular portion 33 to prevent fluid flow there-through in both directions. A resilient sleeve portion 41, centrally disposed around the tubular portion 33, has square cut ends abutting against lower and upper expanders 43, 45 respectively, which are slidably disposed around the tubular portion 33. The enlarged head portion 35 has a flat upper surface or shoulder 47 against which a set of lower slips 49 abut. Similarly, a set of upper slips 51 are disposed around the tubular portion 33 and abut against a collar portion 53 encircling the tubular portion 33. The lower and upper slips 49, 51 respectively, are notched radially and deeply (see FIG. 7) leaving intact a thin web 55 between the several segments of the slips. The slips 49, 51 are mutually cooperable with the respective lower and upper expanders 43, 45 and may be caused to engage the casing 19, in a manner to be described hereinafter. The collar portion 53 has a cylindrical exterior having a diameter which is slightly larger than the outer diameter of the upper segmental slips 51. The collar portion 53 loosely surrounds the tubular portion 33 and the inner surface of the collar portion tapers upwardly and outwardly from the bottom to form a force slope or bevel 57 which merges with an inner cylindrical portion. A grooved, split ratchet-ring 59 encircles the tubular portion 33 and has a lower beveled face 61 which slidably coacts with the force slope or bevel 57. An encircling resilient ring 63 urges the ratchet-ring 59 into engagement with a plurality of circumferential ratchet teeth 65 on the upper exterior surface of the tubular portion 33.

The adapter rod 31 is a rigid cylindrical rod having a female lower end which threadedly engages a tension release portion, or stud 66, of the plug portion 37, and a male upper end which is threadedly received in the lower end of the internal piston and piston rod assembly 25.

The main body portion 23 includes an upper section 67, a middle section 69, and a lower section or setting sleeve 71, all of which are threadedly connected together serially and which have substantially the same outer diameter. The upper end of the upper section 67 is screwed onto a top sub 73 which in turn is bored to slidably receive the lower end of the firing head 27. The upper section 67 is a hollow cylindrical body and has a lower end portion 75 which is screwed onto the top end portion 77 of the hollow cylindrical middle section 69. The top end portion 77 is substantially solid except that it has a central aperture 79 therein, through which a por-

tion of the piston and piston rod assembly 25 passes and in which the rod may reciprocate. The remainder of the middle section 69 is a hollow cylindrical tubular body having a wall thickness that is substantially constant from the bottom thereof to the lower end of the top end portion 77. The lower section or setting sleeve 71 is a short hollow cylindrical tubular member having an enlarged lower end portion 81 which abuts and bears against the upper end of the collar portion 53.

The piston and piston rod assembly 25 includes a length of cylindrical piston rod 83, a first piston 85 which is integrally formed on the rod 83, and a second piston 87 which is screwed onto the lower end of the piston rod 83. The upper end portion of the piston rod 83 is threaded into the lower end portion of the firing head 27. The integrally formed first piston 85 is located (when the tool is retracted or in its inactive position) about midway along the length of the upper section 67 of the main body portion. The portion of the piston rod 83 which extends above the first piston 85 has therein a central axial ignition passage 89 which terminates, at its lower end, in a pair of downwardly sloping branch passages 91, 93, located just below the piston 85. The upper portion end of the piston rod 83 has a frusto-conical passage 95 therein which merges with a cylindrical cell 97 that connects at its lower end with the central axial passage 89, as shown in FIG. 2. As mentioned previously, the piston rod 83 passes through and is reciprocable in the aperture 79 in the top end portion 77. The second piston 87 is located in the lower region of the middle section 69 and it is threaded onto the upper end of the adapter rod 31, as may be seen by referring to FIG. 3. Both of the pistons 85, 87 and the aperture 79 in the top end portion 77 have a plurality of circumferential grooves 99 in each of which there is placed an appropriate fluid sealing material, such as an O-ring gasket 101.

As mentioned previously, the upper end portion of the top sub 73 is bored to slidably receive the lower end of the firing head 27. A shear plug 103, which has a predetermined shear value, is threaded in matchable holes in both the top sub and the firing head for a purpose that will be hereinafter explained. The upper end portion of the firing head 27 has a central axial passage 105 which merges at its upper end with a central axial passage 107 of larger diameter. These axial passages 105, 107 provide communication with the branch passages 91, 93 via the axial passage 89 and cylindrical cell 97.

The quick change assembly 29 threadably engages the upper end portion of the firing head 27 and it is provided with a central axial passage 109 which is adaptable to receive, and in which there is disposed, a firing device 111, commonly termed a "squib." The firing head 27 in other respects is not unlike the firing head shown and described in my co-pending application hereinbefore mentioned.

In the cylindrical axial passage 107 there are both an igniter pellet 113 and an explosive pellet 115, while below them, in the cylindrical cell 97, there is yet another explosive booster pellet 117. Still further below, in an annulus 119, formed by the piston rod 83 and the inner wall portion of the upper section 67 which is below the first piston 85, there is a multi-stage power charge 121 of the present invention. The purpose and relative locations of these several pellets and the power charge will be explained hereinafter.

The piston rod 83 and the inner wall of the upper section 67 which is above the first piston 85 form an annulus 123 in which there is a quantity of lubricating fluid 125. The piston rod 83 and the inner wall of the middle section 69 form another annulus 127 which is a void space; that is to say, it contains only air.

The multi-stage power charge 121 in accordance with a preferred embodiment of the invention, which is delineated in FIG. 8, includes a pair of concentric inner and outer cylindrical tubular members 129, 131 respec-

tively, which form an annulus 133 therebetween. The tubular members may be made of any suitable combustible substance so as to insure progressive end burning action for the charge, for example, they may be made of paper. The annulus 133 is subdivided into four regions which are conveniently designated: a small first region 135, shown at the left hand or top end of the power charge 121, as viewed in FIG. 8; a larger second region 137, adjacent the first region 135; a third region 139, adjacent the second region; and a smaller fourth region 141, at the right end of the power charge 121. The several regions 135, 137, 139 and 141 are each separated at boundaries 143.

In each of the regions 135, 137 and 139 there is a combustible substance; but, for reasons to be presently explained, the region 141 is void. Generally, the combustible substance in the first region or stage 135 is an explosive booster which is easily ignitable and which serves to ignite the relatively fast burning combustible substance in the second region or stage 137. The combustible substance in the second stage is not an explosive, but is a relatively fast burning substance that progressively burns from the top downward toward the boundary 143 separating the substances in the stages 137, 139. When the relatively fast burning substance is about to expire, it ignites the combustible substance in the third region or stage 139. This substance is a relatively slow burning substance compared with the combustible substance in the second stage 137.

It should be understood that the multistage power charge may have any convenient number of stages and it is not intended to limit such power charge to only two main stages 137, 139 and an igniter or booster stage 135.

A typical suitable composition of matter for a relatively fast burning combustible substance may comprise the ingredients: black powder, a filler material, and a binder substance mixed together in the proportions (by weight) of forty percent black powder, forty percent filler material and twenty percent binder substance. Various kinds and forms of these ingredients are available, of course, and suitable ones may be used. A satisfactory filler material is ordinary wood meal; a satisfactory binder substance is an epoxy such as a product marketed under the name of Epon 838 of the Shell Oil Company, or the product Versamid 125 marketed by General Mills, Inc. A typical suitable composition of matter for a relatively slow burning combustible substance may comprise the ingredients: A strong oxidizing substance (for example, potassium nitrate), a filler material, and a binder substance; mixed together in the proportions (by weight) of forty percent potassium nitrate, forty percent filler material and twenty percent binder substance. Various kinds and forms of these ingredients are available, of course, any may be used. Satisfactory filler and binder substances may be those previously mentioned. Combustible substances other than black powder may also be suitable, as will occur to those skilled in the art.

The composition comprising the explosive booster in the first stage 135 may be condensed black powder or any other suitable igniter composition.

The power charge, it will be noticed, is made in a staged form so that its burning progresses in accordance with a predetermined sequence and at a predetermined rate. Thus, the explosive type of substance in the first stage 135, which is the top end, is the first substance that is ignited. This, in turn, ignites the top end of the substance in the second stage 137 and, as mentioned previously, this ignites the top end of the relatively slow burning substance in the third stage 139.

The void region 141, which is variable in size, is simply the space left at the lower end of the charge annulus when the desired volumes of the various stages are in place. The charge tubular members are of length just less than that of the tool charge receiving annulus, so that the

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exposed surface of the first or booster stage is adjacent the lower ends of the branch passages 91, 93.

To understand the use of the device 11, reference may be made initially to FIGS. 2 and 3.

The device 11, as shown in FIGS. 2 and 3 (which, in reality, are sections of one and the same device 11), is suspended in a well bore from the end of a wire line 17 at a predetermined depth location. Now, in order to set the bridge plug 15, an electrical circuit is closed at the surface, in any suitable manner and by means of an appropriate apparatus, and an electrical current is sent via the wire 17 to the firing device or squib 111. The squib 111 becomes heated and ignites the igniter pellet 113 which, then, ignites the explosive booster pellet 115. As the booster pellet 115 burns, the heated gases of combustion travel down the axial passage 105 and cause the lower booster pellet 117 to ignite and burn. The heated gases of combustion produced by the burning lower booster pellet 117, in like manner, travel down the axial ignition passage 89 and the branch passages 91 and 93. As the heated gases of combustion emerge from the branch passages 91, 93, they impinge upon and ignite the combustible substance in the topmost or first stage 135 of the multi-stage power charge 121. It was mentioned previously that the combustible substance in this first stage ignites easily, and it ignites the relatively fast burning substance in the second stage 137. Now, while this latter substance burns, the gas pressure generated in the annulus 119 builds up rapidly and the force of the gas on the first piston 85 increases proportionately until the shear plug 103 shears. Initially thereafter, the main body portion 23 moves downward relative to the piston 85 because the mass of the piston and piston rod assembly 25 and all of the other components attached thereto is proportionately greater than the mass of the main body portion 23 and its attached components. The downward movement of the main body portion 23 and connected components causes the upper segmental slips 51 to slide downward on the upper expander 45. The thin web 55 between the several segments of each of the slips breaks and the segment of the upper slips 51 are snapped or forced downward and outward into engagement with the inner wall of the casing 19, as shown in FIG. 5. The lower segmental slip 49 tends to remain at its initial level, but the lower expander 43, cooperating with the lower segmental slips 49, breaks the thin web 55 and the segments of the lower slips 49 are also snapped or forced upward and outward into engagement with the inner wall of the casing 19. Thereafter, the lower and upper expanders 43, 45 respectively, compress the resilient sleeve portion 41 and urge it outwardly and into engagement with the inner wall of the casing 19.

It will be remembered that so far only the relatively fast burning combustible substance in the region 137, or second stage, is burning. When it is nearly consumed, it ignites the third stage, or the relatively slow burning combustible substance in the region 139. Thereupon, the gases of combustion produced by the third stage continues to develop and exert pressure on the relatively moving parts.

While the main body portion 23 and the connected components are moving downward, the tubular portion 33 moves upward relative to the ratchet device 59. When this relative movement ceases, the teeth of the ratchet device 59 engages the ratchet teeth 65 on the upper tubular portion 33. Later, when the gas pressure applied forces are reduced and when the bridge plug is set, the tubular portion 33 is prevented from moving downward because the reactive forces acting at the bevel surfaces 57, 61 cause the slips 49, 51 and the ratchet ring 59 to grip more tightly. After the slips are set and the resilient sleeve or packer 41 has been compressed enough to provide a sufficient seal, the continued burning of the third stage produces a gaseous pressure applied force which causes the upper threaded portion or stud 66 to shear. Thereafter, the setting tool device 11 is released from the

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bridge plug 15 and may be retrieved, leaving the bridge plug 15 set in the casing 19.

It will be convenient and helpful in understanding the use of the device 11 to recapitulate the steps in the sequence of setting events in relation to the time and pressures developed within the annulus 119 by the burning of the multi-stage power charge 121. Reference may be made to FIG. 9 wherein there is illustrated a graph generally indicating the pressures developed by the burning multi-stage power charge (plotted therein as ordinates) and time (plotted as abscissas). To begin with, the time commences at point O which corresponds to the ignition of the second stage, or the relatively fast burning combustible substance in the region 137. This substance burns for a period of time and generates gaseous products of combustion which develop pressure within the annulus space 119 or the combustion chamber. The gaseous pressure continues to build up until the force acting on the first piston 85 is great enough to cause the shearing of the shear plug 103. Thereafter, the main body portion 23, initially, is free to move downward relative to the piston and piston rod assembly 25. Now then, as the pressure within the combustion chamber continues to increase, the following events occur seriatim: the main body portion, by way of the setting sleeve 71, exerts a force on the collar portion 53 which is transmitted to the upper slips 51. The piston and piston rod assembly 25 also exerts a like force on the lower slips 49. The thin web 55 between the several segments of the slips breaks easily and the segments of slips, being free, snap into engagement with the inner wall of the casing 19. While the slips are being moved into casing wall engagement, the several O-rings in the device 11 are being urged into activity and seating engagement in their respective locations. As soon as the slips are brought into engagement with the inner casing wall, the force of the gaseous pressure in the combustion chamber is now directed to compressing the resilient sleeve or packer 41. At first, it moves rapidly toward and engages the inner wall of the casing. At or about this time, which is indicated as the region A of the solid line curve of FIG. 9, the burning second stage 137, which is about to expire, ignites the relatively slow burning third stage 139. Whereupon, the gaseous pressure developed by the burning third stage 139 continues compressing of the packer 41 and urging it into sealing engagement with the inner wall of the casing as the gaseous pressure continues to build up. This condition is shown in FIG. 9 by the increase in pressure between the region designated A and the point B, with the point B representing the maximum pressure developed by the power charge. It is at this maximum pressure, after the packer has been fully compressed, that the stud 66 reaches its ultimate tensile value and shears. Immediately, the device 11 is released and the gaseous pressure drops to an intermediate level represented by the point C of FIG. 9, at which level it may remain, as indicated by the discontinuous line to the right thereof, until released by further suitable means.

It should be mentioned that the pressure-time relation, shown graphically in FIG. 9 by the solid-line curve, may be expected from a multi-stage power charge in which the relative weights of the second and third stage charges are approximately equal. In some applications, however, it may be preferable to use second and third stage charges that have unequal weight ratios. For example, the pressure-time curve, which is shown in FIG. 9 as a dotted line, may be expected from a multi-stage power charge wherein there is a greater amount of the relatively fast burning substance (stage two) than the relatively slow burning substance (stage three). It will be appreciated then, that the region A' of the dotted curve has the same significance as the region A, described hereinbefore; likewise, the points B' and C' have the same significance as the points B and C, which were described hereinbefore.

It should be clear then that the sequence of mechanical

steps which comprise the setting of the bridge plug 15, may be correlated and shown in a time-pressure graphical relation, such as is delineated in FIG. 9.

It is a feature of the present invention that the multi-stage power charge thereof comprises a combustible stage such as the second stage described herein which produces a rapid initial build-up of gaseous pressure in the setting tool combustion chamber. The rapid initial build-up of activating gaseous pressure, such as is shown in FIG. 9 and which occurs between the point O and the regions A or A', is desirable for several reasons. Firstly, the freed segments of the bridge plug or packer slips are snapped into position against the inner wall of the casing before they may become inoperatively or deleteriously disarranged. It is clear that the slip segments, should they be disarranged, could cause a malfunction of the bridge plug device; or some segments might become completely free and fall down the well bore, and these could cause difficulty at a later time. Secondly, the rapid movement of the relatively moving parts of the device 11 activates the several O-ring seals and more effectively sets them. It has been found that O-rings which are worn may still be effectively used if they are activated quickly. The power charge of the present device readily and easily accomplishes this.

Another feature of the present invention is that the gaseous pressure developed by a stage such as the burning third stage hereinbefore described, increases slowly and over a sufficiently long period of time to allow the packer or bridge plug compressible material time to effectively compress and seal in the casing. Furthermore, the rate of increase of pressure between the region A and the point B (or between A' and B') is calculated to avoid a shock shearing force on the stud 66 prior to the time when the packer is effectively set. Moreover, it is desirable to rapidly move the packer compressible material into engagement with the wall of the casing in order to avoid the possibility that high pressure gases or fluid flowing from the well will erode the packer and casing, a condition which is usually termed throttling or wiredrawing. It is clear, then, that the multi-stage power charge of the present invention moves the packer, in the manner described, with dispatch, and that the condition of throttling or wiredrawing is effectively obviated.

Thus, in accordance with one aspect of the invention there is provided a multi-stage power charge for use with a bridge plug or packer setting tool, with one burning stage or the power charge being capable of generating gaseous pressure in the tool combustion chamber at a rate faster than a subsequent burning stage, and with the said gaseous pressure reaching a maximum value during the burning of the power charge final stage. The time interval between ignition of the first burning stage of the power charge and the reaching of maximum combustion chamber pressure is preferably within one second. In accordance with another aspect thereof, the invention contemplates that one or more successive stages of the power charges burning seriatim will be capable of developing cumulatively a partial gaseous pressure in the tool combustion chamber the value of which is in the range of up to a ninety percent part of the maximum pressure developed by the power charge, with this partial pressure being reached at a time prior to the commencement of burning of the charge last stage. In accordance with another aspect thereof, the invention contemplates that the power charge stages will burn seriatim so as to cumulatively develop gaseous pressure in the tool combustion chamber in such manner that the arithmetic mean rate of increase of pressure during the burning of the charge last stage will be less than the ratio of maximum pressure developed by said charge divided by the interval of time required to achieve the maximum pressure, with the maximum pressure being developed during the burning of the charge last stage. In other words, the tool will develop gaseous pressure such that the average slope of the pressure-time

curve (for example, solid line curve of FIG. 9), during the burning of the charge last stage (between points A and B of FIG. 9) is less than the slope of a line drawn from the point of time and pressure where the charge first burning stage begins to burn to the point of time and maximum pressure developed (a line from point O to point B in FIG. 9).

While I have shown by invention in only one form, it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various changes and modifications without departing from the spirit thereof.

I claim:

1. In combination with a well device adapted to be operated and set in a well bore and fluid actuable means operatively connected to said well device, said means including a cylinder and a piston slidable in said cylinder; a multi-stage power charge disposed in said device, with one burning stage thereof being capable of generating gaseous pressure in said cylinder at a rate that is faster than a subsequent burning stage, and with the said gaseous pressure continuously increasing and reaching a maximum value during the burning of the final stage of said multi-stage power charge; and means for igniting said power charge.

2. In combination with a well device adapted to be operated and set in a well bore and fluid actuable means operatively connected to said well device, said means including a cylinder and a piston slidable in said cylinder; a multi-stage power charge disposed in said device, with one burning stage thereof being capable of generating gaseous pressure in said cylinder at a rate that is faster than a subsequent burning stage, and with the said gaseous pressure continuously increasing and reaching a maximum value during the burning of the final stage of said multi-stage power charge and within one second of time; and means for igniting said power charge.

3. In combination with a well device adapted to be operated and set in a well bore and fluid actuable means operatively connected to said well device, said means including a cylinder and a piston slidable in said cylinder; a multi-stage power charge disposed in said device with one or more successive stages thereof burning seriatim and being capable of developing cumulatively a partial gaseous pressure in said cylinder the value of which is in the range of up to a ninety percent part of the maximum pressure developed by said power charge, said partial pressure being reached at a time prior to the commencement of burning of the last stage of said power charge and said pressure continuously increasing until said maximum pressure is reached; and means for igniting said power charge.

4. In combination with a well device adapted to be operated and set in a well bore and fluid actuable means operatively connected to said well device, said means including a cylinder and a piston slidable in said cylinder; a multi-stage power charge disposed in said device with the stages thereof being capable of burning seriatim so as to cumulatively develop continuously increasing gaseous pressure in said cylinder in such a manner that the arithmetic mean rate of increase of pressure during the burning of the last stage of said power charge is less than the ratio of the maximum pressure developed by said power charge divided by the interval of time required to achieve said maximum pressure, said maximum pressure being developed during the burning of the last stage of said multi-stage power charge; and means for igniting said power charge.

5. In combination with a well device adapted to be operated and set in a well bore and fluid actuable means operatively connected to said well device, said means including a cylinder and a piston slidable in said cylinder; a multi-stage power charge disposed in said device with the stages thereof being capable of burning seriatim so as to cumulatively develop continuously increasing gaseous pressure in said cylinder with one said burning stage being

capable of generating said gaseous pressure at a rate that is faster than a subsequent burning stage; said gaseous pressure being developed in such a manner that the arithmetic mean rate of increase of pressure during the burning of the last stage of said power charge is less than the ratio of the maximum pressure developed by said power charge divided by the interval of time required to achieve said maximum pressure; said maximum pressure being developed during the burning of the last stage of said multi-stage power charge; and means for igniting said power charge.

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References Cited by the Examiner

UNITED STATES PATENTS

2,640,547	6/1953	Baker et al.	166—63
2,807,325	9/1957	Webb	166—63
3,002,559	10/1961	Hanes	166—63
3,026,939	3/1962	Sweetman	166—63 X
3,029,873	4/1962	Hanes	166—120 X

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