Dec. 12, 1967 H. L. McGILL 3,357,488

WELL TOOL CONTROL APPARATUS

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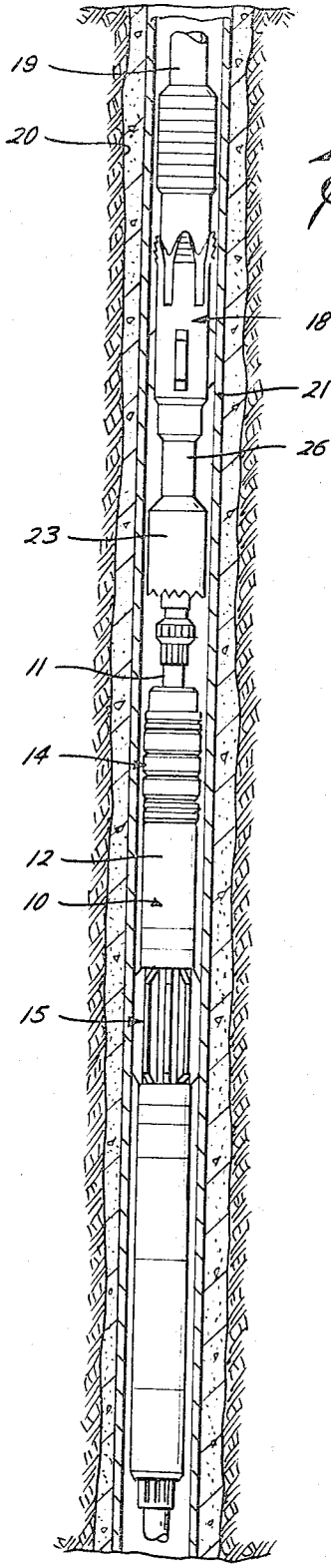
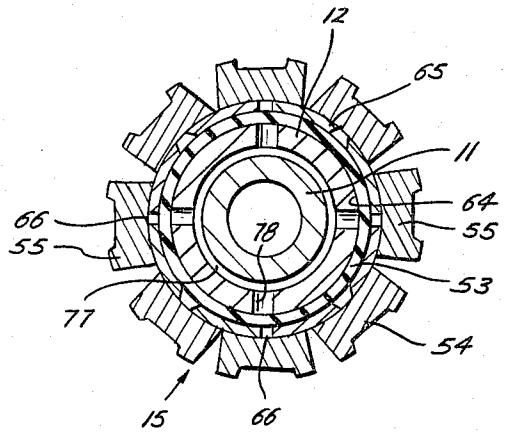


Fig. 1

Fig. 4



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Fig. 2A

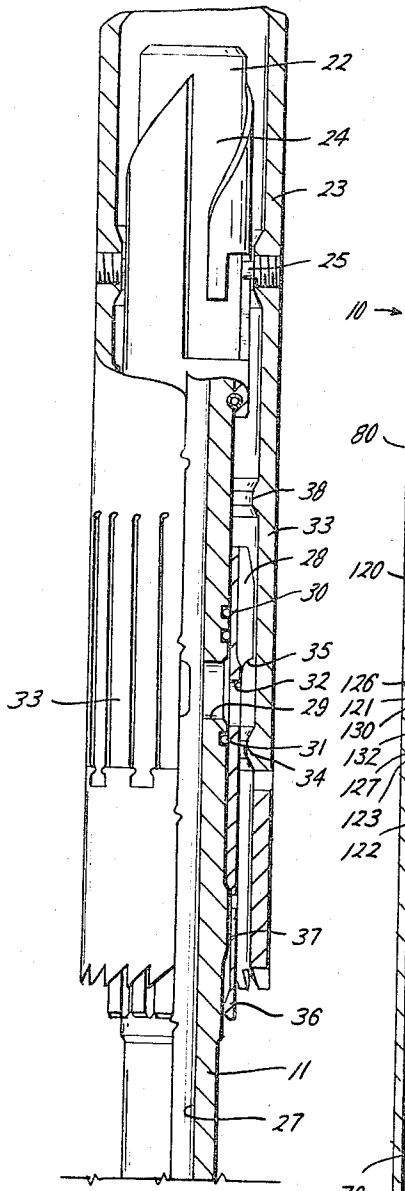


Fig. 2B

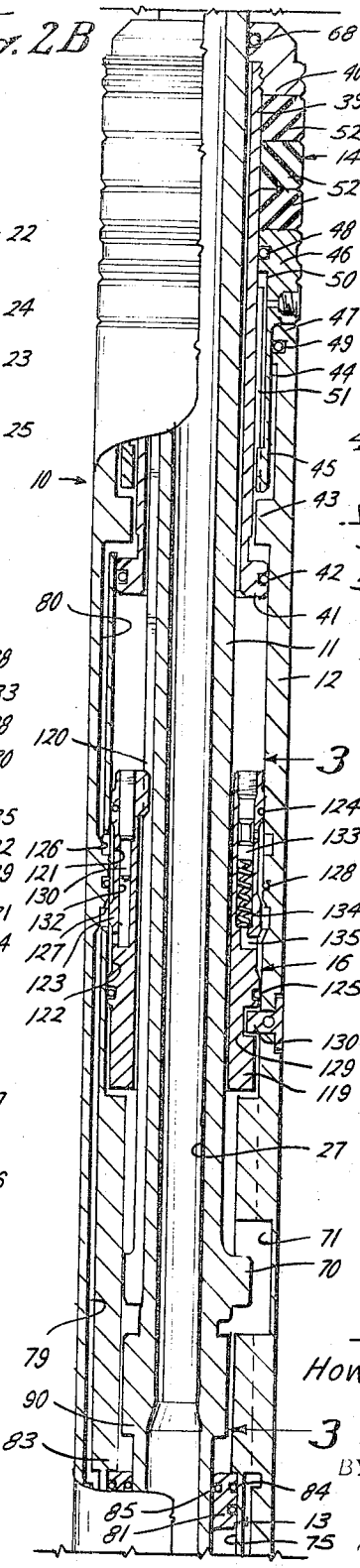
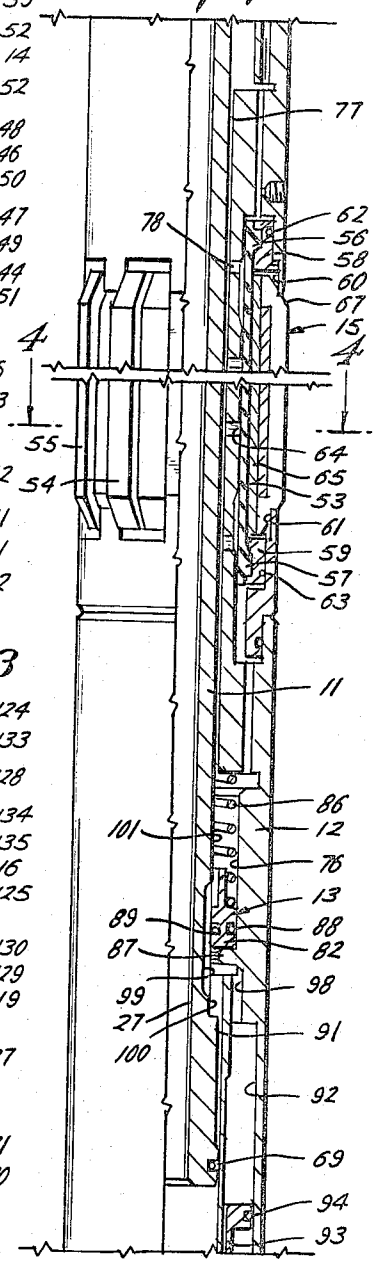


Fig. 2C



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Fig. 2D

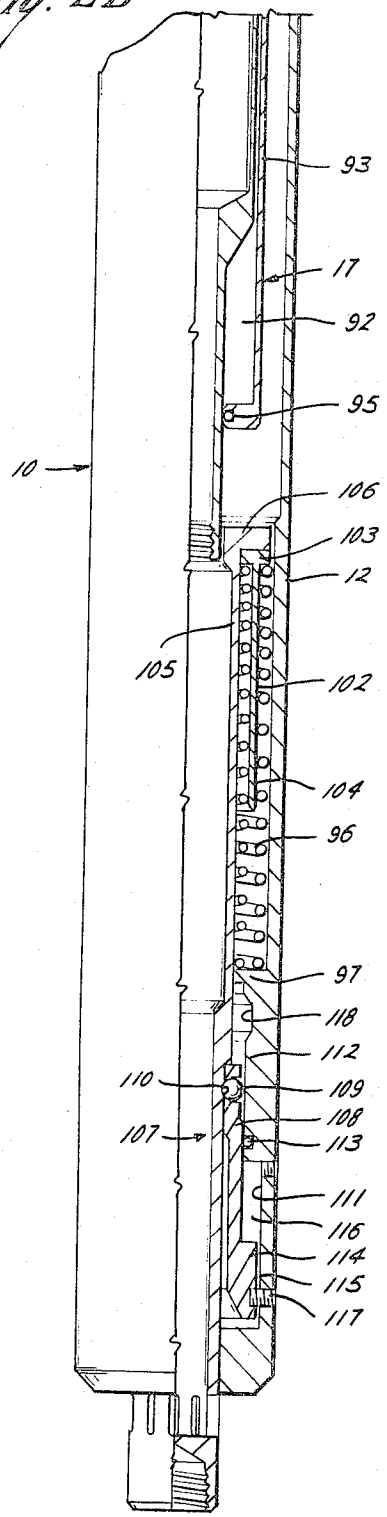
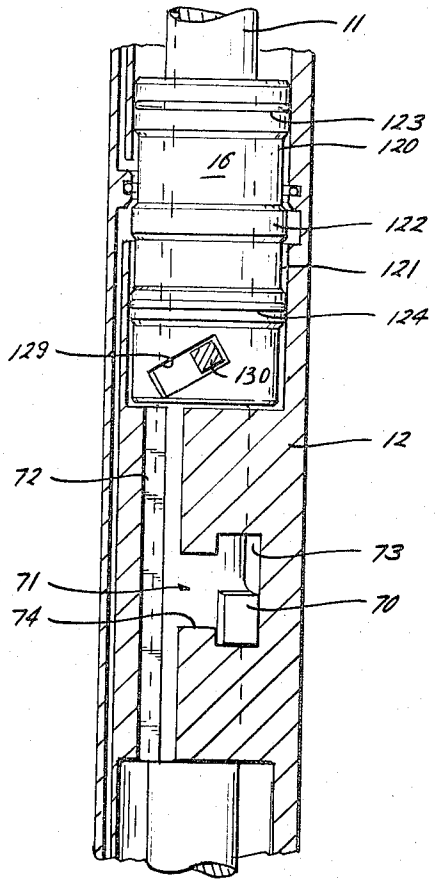


Fig. 3



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Fig. 5A

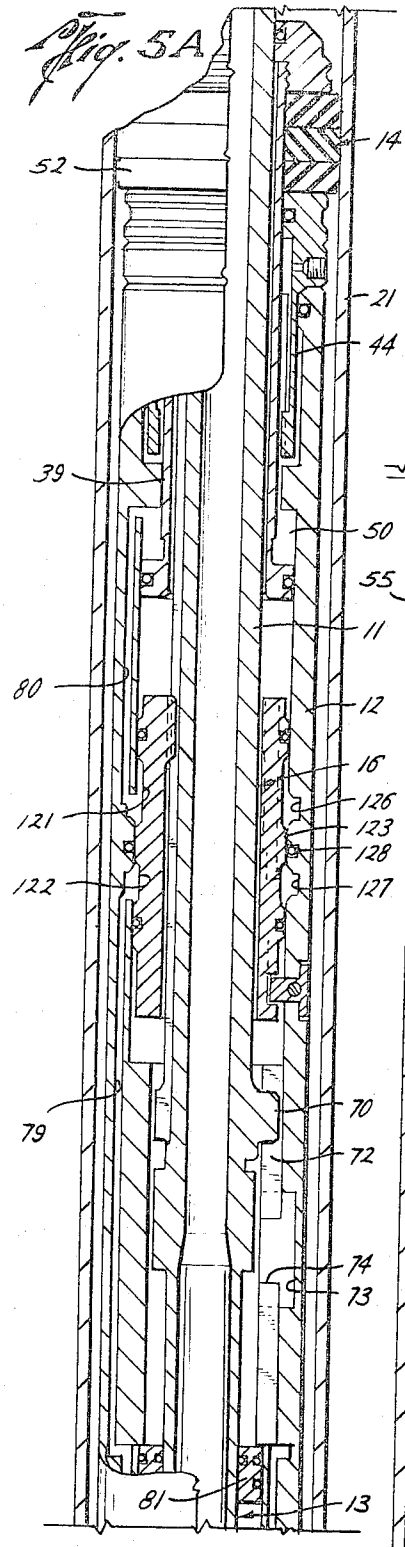


Fig. 5B

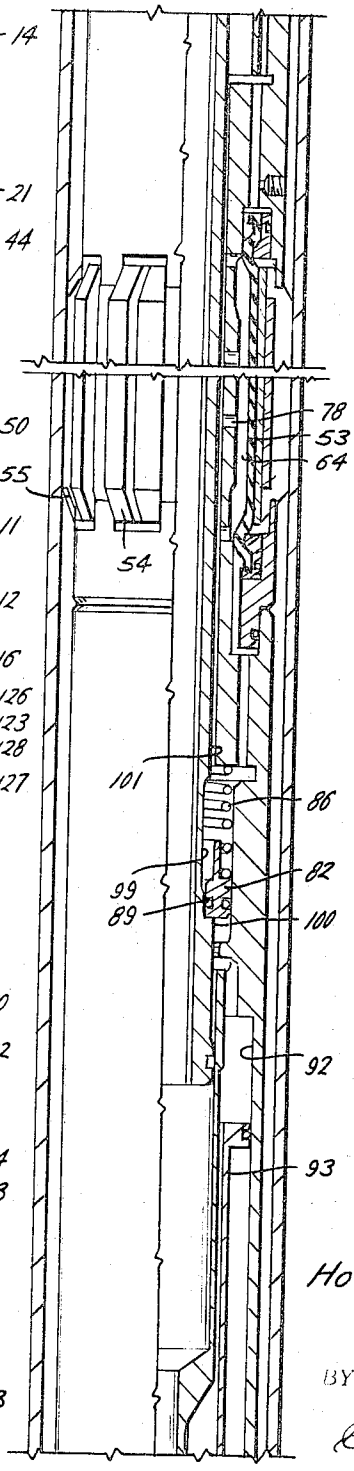
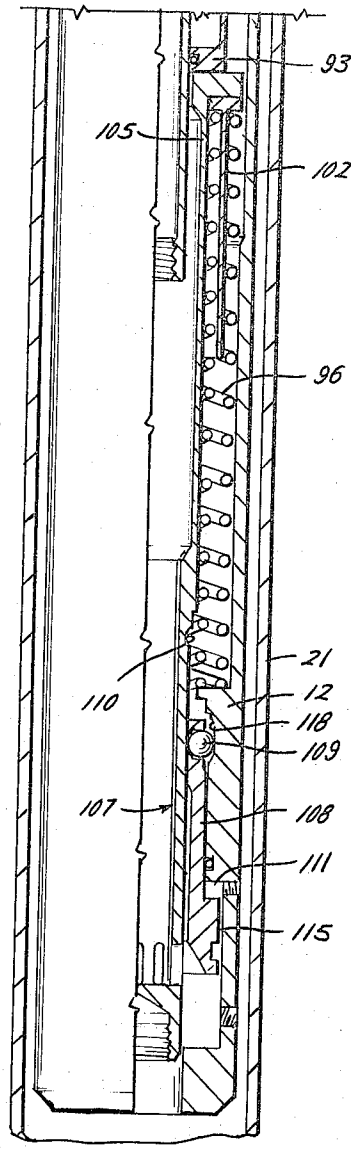


Fig. 5C



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Fig. 6

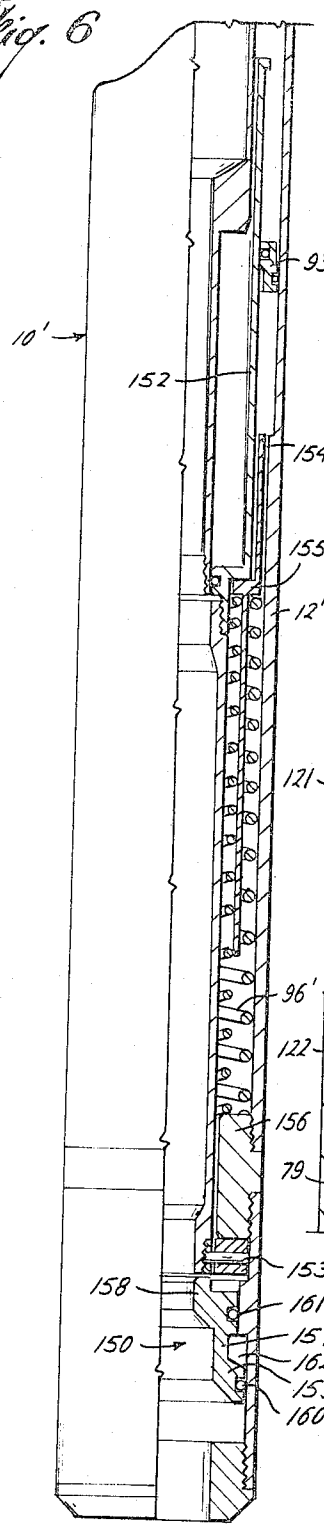
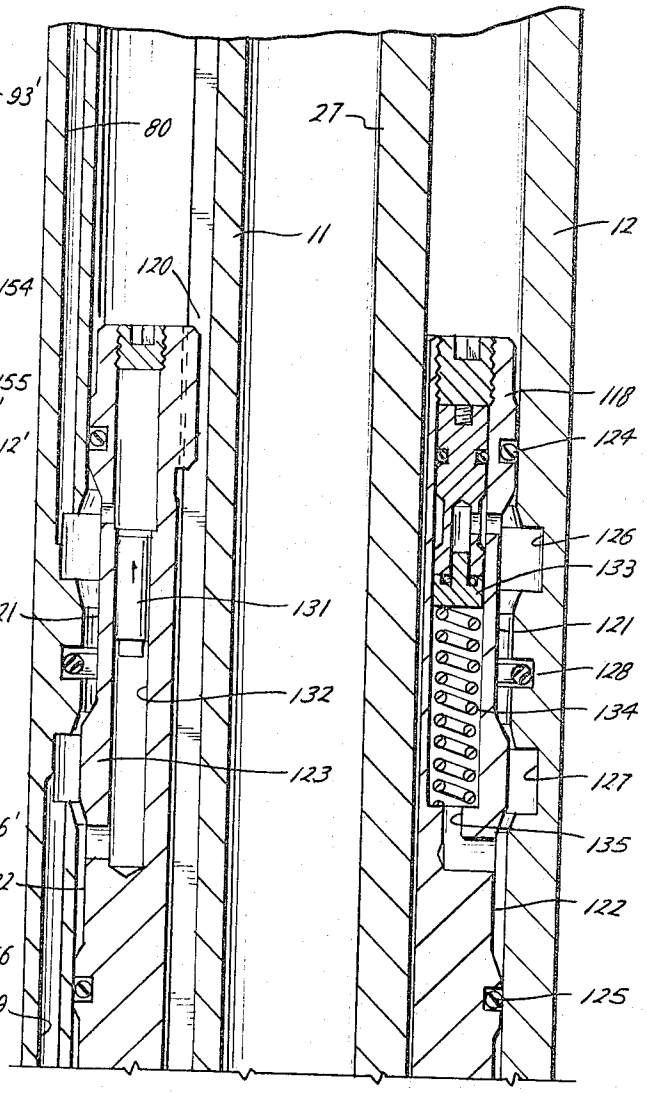


Fig. 7



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3,357,488

WELL TOOL CONTROL APPARATUS

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Filed Dec. 10, 1965, Ser. No. 512,857
10 Claims. (Cl. 166—120)

This invention relates to control apparatus for well tools; and, more particularly, to controls for packing apparatus which, when actuated, will maintain the packing apparatus anchored and sealingly engaged in the well against pressure differentials acting on it from either direction by forces proportionately related to these acting differentials.

In conducting such well completion operations as acidizing, cementing, or fracturing, a full-opening well packer dependently coupled from a tubing string is positioned at a particular depth in a cased well and the packer set to isolate the formation interval to be treated from the remainder of the well bore thereabove. Treating fluids are then pumped downwardly at high pressure through the tubing and packer and introduced into the formation being treated through perforations appropriately located in the casing.

In those instances where a well having several producing formations is being completed, a selectively operable bridge plug is usually dependently coupled beneath the full-opening packer. Such a bridge plug permits intervals of selective length to be packed-off for selective treatment of different formation zones with only a single trip into the well. It will be appreciated that during the course of such completion operations, these packing apparatus are usually subjected to high fluid pressures acting alternately from both above and below them. Thus, these packers and bridge plugs must be firmly sealed and securely anchored against pressure differentials acting in either longitudinal direction.

Accordingly, it is an object of the present invention to provide new and improved means for controlling packing apparatus having hydraulically actuated extendible packing means and wall-engaging anchoring means, which control means maintain these extendible means in sealing and anchoring engagement with forces proportionately related to pressure differentials between fluids in the well above and below the apparatus.

Packing apparatus provided with control means arranged in accordance with the invention includes an actuating member and hydraulic means that are selectively operable thereby for initially setting the packing element and anchoring the apparatus in the well bore with predetermined engaging forces and, thereafter, respond to pressure differentials across the packing apparatus to maintain the packing element and wall-engaging means in engagement with forces that are proportionately related to these differentials.

The novel features of the present invention are set forth with particularity in the appended claims. The present invention, both as to its organization and manner of operation together with further objects and advantages thereof, may best be understood by way of illustration and example of certain embodiments when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a view of a full-bore packer and a bridge plug with the control means of the present invention and depicted as they would appear within a well bore;

FIGS. 2A–2D are successive, detailed cross-sectional views of an embodiment of a bridge plug having means for controlling hydraulically actuated packing means and anchoring means in accordance with the present invention;

FIG. 3 is a schematic view illustrating particular details

of indexing and locking grooves employed with the bridge plug of FIG. 2;

FIG. 4 is a cross-sectional view taken along the lines 4—4 of FIG. 2C;

FIGS. 5A–5C are successive views similar to FIGS. 2B–2D but depicting the bridge plug as it will appear when set within a well bore;

FIG. 6 is a view of an alternate embodiment of a portion of the bridge plug of FIG. 2; and

FIG. 7 is an enlarged view showing the control means of the present invention.

In general, the retrievable bridge plug **10** of the present invention is comprised of an actuating body or mandrel **11** that is telescoped within a tubular housing **12** and selectively movable therein between an intermediate neutral position (FIG. 2) and an operative position (FIG. 5) in which the mandrel is free to shift a limited distance either upwardly or downwardly relative to the housing. Pressure-developing means **13** are included which, as the mandrel **11** shifts relative to the housing **12**, will develop sufficient pressure to extend pressure-responsive packing means **14** and anchoring means **15** outwardly into firm engagement with an adjacent wall in a well bore. Control means **16**, which are selectively operated by movement of the mandrel **11** into and out of their operative position, are provided to regulate the hydraulic pressure applied to the packing means **14** and insure that the packing means remain sealingly engaged irrespective of further shifting of the mandrel until it is returned to its neutral position.

By employing selectively releasable pressure-developing means **17** that release under either a predetermined hydrostatic pressure in the well bore or after a predetermined time delay, an initial pressure is subsequently developed to urge the anchoring means **15** against the well bore wall with sufficient force to secure the housing **12** for moving of the mandrel **11** relative thereto.

Since those skilled in the art will recognize that such a well tool is typically comprised of separate tubular elements threadedly connected to one another to facilitate its manufacture and assembly, the drawings have been somewhat simplified by showing some of these separate elements as a single member for purposes of greater clarity.

Turning now to FIG. 1, a typical full-bore packer **18** is dependently connected to a tubing string **19** and positioned within a well bore **20** having a casing **21** set therein. A retrievable bridge plug **10** arranged in accordance with the present invention is releasably coupled by a fishing neck **22** to an overshot **23** dependently connected beneath the packer **18**.

Matched J-slots **24** (FIG. 2A) are arranged on opposite sides of the fishing neck **22** to cooperatively receive inwardly projecting lugs **25** on the overshot **23** whenever it is lowered over the fishing neck. After the lugs **25** have entered the open upper end of the long portions of the J-slots **24**, the lugs are lockingly engaged in the closed short portion of the J-slots by a concerted application of counter-clockwise torque and a slight upward pull on the tubing string **19**. Conversely, the overshot **23** is selectively disengaged from the fishing neck **22** by lowering the tubing string **19** slightly, torquing it to the right, and then pulling upwardly. By employing such a releasable coupling, the bridge plug **10** can be set at the lower limit of a particular formation interval and the packer **18** uncoupled and subsequently set thereabove irrespective of the length of the tubing sub **26** connecting them.

Fluid communication through the mandrel bore **27** is selectively controlled by an annular valve member **28** which is slidably disposed around the mandrel **11** immediately around lateral bypass ports **29** therein and

fluidly sealed thereto by O-rings 30 and 31 straddling the bypass ports. Lateral ports 32 are appropriately arranged in the slidable valve member 28 to register with the bypass ports 29 whenever the valve member is in the position illustrated in FIG. 2. The slidable valve member 28 is arranged to be shifted longitudinally by the overshot 23 so that the ports 29 and 32 are brought into register as the overshot is being engaged over the fishing neck 22 (FIG. 2A) and the bypass ports are covered by the valve member whenever the overshot is removed.

Whenever the overshot 23 is being removed, a group of dependent resilient fingers 33 spaced around the lower portion of the overshot have inwardly projecting shoulders 34 that engage a shoulder 35 on the sliding valve member 28 to pull it upwardly and close the bypass ports 29. As the valve member 28 is pulled upwardly, depending resilient fingers 36 around the lower end of the valve member are cammed outwardly as they pass over an annular shoulder 37 around the mandrel 11. After clearing the mandrel shoulder 37, the lower ends of these fingers 36 then engage the annular shoulder to hold the slidable valve member 28 in its uppermost or port-closed position (not shown) after the overshot 23 has been removed. A shoulder 38 projecting inwardly from the central portion of the overshot 23 engages the valve member 28 and shifts it downwardly to its open position (FIG. 2A) whenever the overshot is coupled to the fishing neck 22.

As seen in FIG. 2B, the pressure-responsive packing means 14 include a slidable sleeve member 39 having an outwardly enlarged upper end 40 and an outwardly enlarged lower end 41 that is telescopically fitted within the upper portion of the tubular housing 12 and fluidly-sealed thereto by an O-ring 42 below an inwardly projecting housing shoulder 43. A shorter slidable sleeve member 44 is telescopically arranged around the central portion of the other setting sleeve 39 and has a lower end 45 extending into the housing 12 above the housing shoulder 43 and a projecting, outwardly enlarged upper end 46 that is shouldered on the upper housing end 47 and fluidly sealed to the inner sleeve by an O-ring 48. An O-ring 49 in the upper housing end 47 fluidly seals the shorter outer setting sleeve 44 to the housing 12 and defines an enclosed space 50 between the setting sleeves 39 and 44 and the other O-rings 42 and 48. An elongated external spline 51 extending longitudinally along the inner setting sleeve 39 is cooperatively received within complementary internal grooves in the housing shoulder 43 and shorter outer sleeve 44 to co-rotatively secure the three members to one another and limit their relative movement to longitudinal telescopic travel.

Elastomeric packing means 14, such as a plurality of stacked annular elements 52 mounted around the exposed portion of the inner sleeve, are arranged between the outwardly enlarged upper ends 40 and 46 of the sleeves 39 and 40 to be foreshortened thereby and expanded outwardly whenever the setting sleeves are relatively telescoped together. Conversely, longitudinal movement in the opposite direction of the sleeve ends 40 and 46 as the setting sleeves 39 and 44 expand allow the packing rings 52 to relax and return to their normal position.

Thus, it will be appreciated that, upon application of sufficient hydraulic pressure in the enclosed space 50, the setting sleeves 39 and 44 will be telescoped. As the setting sleeves 39 and 44 contract, the elastomeric elements 52 will be foreshortened and expanded radially outwardly against the casing wall. By appropriately selecting elements 52 having particular elasticity and dimensions suitable for a given range of casing diameters, it can be readily determined that, for a given hydraulic pressure in the enclosed space 50, the elements will be urged against the casing 21 with a force proportionately related to this hydraulic pressure. Accordingly, those skilled in the art will understand that by applying at least a predetermined hydraulic pressure in the enclosed space 50, the elastomeric elements 52 will be sealingly engaged against the casing 21 with a force sufficient to withstand well bore pressure differentials up to a particular magnitude.

Mounted around the central portion of the housing 12 is the hydraulically actuated, radially expansible anchor 15 (FIG. 2C), with parts thereof as also shown in cross-section in FIG. 4. This anchor 15 includes an expansible elastomeric sleeve 53 encircling the central portion of the housing 12 with a plurality of elongated wall-engaging members 54 and 55 being longitudinally mounted uniformly around the periphery of the sleeve. The enlarged upper and lower ends 56 and 57 of the elastomeric sleeve 53 are secured by slidable annular retainers 58 and 59 within opposite peripheral recesses 60 and 61 around the housing 12. O-rings 62 and 63 around the retainers 58 and 59 fluidly seal the sleeve ends 56 and 57 within the recesses 60 and 61 to provide a fluid-tight space 64 between the sleeve 53 and housing 12.

Each of the casing-engaging members 54 and 55 is elongated and has a thick, arcuate cross-section (FIG. 4). Alternate ones of the casing-engaging members 54 are centrally aligned and mounted on the outer convex surface of relatively thin, elongated, arcuate backing members 65.

A sufficient number of these mounted members 54 are disposed around the periphery of the elastomeric sleeve 53 that the backing members 65 substantially encompass the sleeve. The remaining casing-engaging members 55 are unmounted and alternately disposed between the mounted casing-engaging members 54 in such a manner that the unmounted members 55 straddle adjacent backing members 65 and cover the gaps 66 therebetween.

The ends of the casing-engaging members 54 and 55 are beveled, as at 67 (FIG. 2C) for reception within the opposed annular housing recesses 60 and 61. It will be appreciated that, although the casing-engaging members 54 and 55 will move radially outwardly whenever the elastomeric sleeve 53 is inflated, the beveled ends 67 of the members cannot escape from the housing recesses 60 and 61.

By applying hydraulic pressure within the fluid-tight space 64, the casing-engaging members 54 and 55 will be urged against the casing 21 with a force proportionately related to this pressure. Thus, by appropriately selecting the materials and contact surface areas for the casing-engaging members 54 and 55, it can be readily determined that a particular hydraulic pressure in the fluid-tight space 64 will secure the bridge plug 10 against longitudinal shifting by pressure differentials in the well up to a particular magnitude.

The actuating mandrel 11 is movably disposed through the inner setting sleeve 39 and extends on downwardly into the housing 12. O-rings 68 and 69 at each end of the mandrel 11 respectively fluidly seal the mandrel to the inner sleeve 39 and lower end of the housing 12. To establish the longitudinal position of the mandrel 11 relative to the housing 12, an outwardly projecting lug 70 on the mandrel is confined within an inwardly directed T-shaped slot 71 formed in the inner wall of the housing. As shown schematically in FIG. 3, the T-slot 71 has an elongated portion 72 extending longitudinally along the housing 12 and a shorter longitudinal portion 73 spaced apart therefrom and connected thereto by a transverse portion 74 extending between the centers of the longitudinal slot portions.

As will be seen from FIG. 3, so long as the mandrel lug 70 is confined in the shorter slot portion 73, the mandrel 11 is substantially restrained from moving longitudinally relative to the housing 12. However, by rotating the mandrel 11 in a clockwise direction to bring the lug 70 through the transverse slot portion 74 into the elongated slot portion 72, the mandrel is then free to shift longitudinally relative to the housing 12 a distance determined by the length of the elongated slot portion.

Turning now to the pressure-developing means 13 for the bridge plug 10, the housing 12 is formed in such a manner as to provide an annular chamber 75 (FIG. 2B)

above the upper end of the anchor 15. A similar annular chamber 76 (FIG. 2C) is also formed below the lower end of the anchor 15. An annular clearance space 77 (FIG. 2C) between the mandrel 11 and housing 12 provides fluid communication from the upper chamber 75 to the lower chamber 76. A plurality of radial ports 78 through the housing 12 adjacent the elastomeric sleeve 53 provide fluid communication from this clearance space 77 into the sealed space 64 underneath the elastomeric sleeve. Longitudinal passages 79 and 80 through the housing 12 provide fluid communication from the annular chambers 75 and 76 to the enclosed space 50 between the setting sleeves 39 and 44. Filling ports with closure members (not all shown) are provided at appropriate locations for introducing a suitable hydraulic fluid into the hydraulic system.

The upper end of the upper annular chamber 75 and the lower end of the lower annular chamber 76 are respectively closed by annular piston members 81 and 82 which are slidably mounted relative to both the housing 12 and mandrel 11. The upper slidable piston member 81 (FIG. 2B) is adapted to engage a downwardly directed shoulder 83 formed in the housing 12 at the upper end of the upper chamber 75. Annular grooves around the outer and inner surfaces, respectively, of the upper piston member receive O-rings 84 and 85 which fluidly seal the slidable piston member 81 relative to the housing 12 as to the mandrel 11.

The lower slidable piston member 82 (FIG. 2C) is biased downwardly by a spring 86 so that the lower piston member normally rests against an upwardly directed shoulder 87 formed in the housing 12 at the lower end of the lower chamber 76. Similarly, external and internal annular grooves around the piston member 82 receive O-rings 88 and 89 to fluidly seal the slidable piston member relative to both the housing 12 and the mandrel 11.

A shoulder 90 (FIG. 2B) located on the mandrel 11 a short distance above the upper slidable piston 81 is so arranged that whenever the mandrel shifts downwardly, the shoulder will engage the upper piston and force it downwardly. Similarly, a second shoulder 91 (FIG. 2C) is provided on the mandrel 11 to engage and shift the lower piston member 82 upwardly whenever the mandrel shifts in that direction. It will be appreciated, therefore, that with a suitable fluid in the above-described hydraulic system, longitudinal shifting of the mandrel 11 in either direction will develop a uniform pressure throughout the system that is related to the distance that the mandrel shifts. Thus, as previously described, this developed hydraulic pressure is employed to telescope the setting sleeve 39 and 44 for expanding the packing elements 52 and to press the casing-engaging members 54 and 55 against the casing.

An annular compensating chamber 92 (FIG. 2C) is formed in the housing 12 beneath the lower piston member 82 to maintain a supply of fluid in the hydraulic system as well as to compensate for thermal expansion of the hydraulic fluid. The lower end of this annular chamber 92 is closed by a slidable, annular compensating piston member 93 having O-rings 94 and 95 around its outer and inner surfaces which fluidly seal the compensating piston relative to the housing 12. Means, such as springs 96 underneath the compensating piston 93 and resting on an upwardly facing housing shoulder 97, are provided to accommodate thermal expansion of the hydraulic fluid as well as to bias the compensating piston against the hydraulic fluid. For reasons to be explained shortly, the springs 96 are releasably restrained to initially prevent them from engaging the compensating piston 93.

Selectively controlled fluid communication is provided between the compensating chamber 92 and the remainder of the hydraulic system through a housing passage 98 and an annular clearance space formed by a reduced-diameter portion 99 around the mandrel 11. This reduced-diameter portion 99 is arranged to be normally in juxtaposition with the lower piston 82 whenever the mandrel 11 is in its intermediate neutral position as determined by the mandrel lug 70 being confined within the shorter slot 73. When, however, the mandrel 11 has been so manipulated to shift the lug 70 into the longer slot 72 and the mandrel is shifted longitudinally only a slight distance in either direction, the inner O-ring 89 within the lower piston member 82 fluidly seals the piston to the mandrel at either 100 or 101 depending upon the direction in which the mandrel has been shifted.

Accordingly, it will be seen that so long as the mandrel 11 is in a "neutral" or intermediate position (as determined by the lug 70 being within the short slot 73), the mandrel is substantially restrained from shifting longitudinally in either direction and the upper and lower piston members 81 and 82 will be substantially in the positions illustrated in FIG. 2 with the mandrel shoulders 90 and 91 separated therefrom. When the mandrel 11 is in the above-mentioned intermediate position, the reduced-diameter mandrel portion 99 will permit free communication of hydraulic fluid from the compensating chamber 92 into the remainder of the hydraulic system above the lower piston 82. This communication will allow the fluid in the hydraulic system to expand as its temperature increases during a descent into a well bore. It will be recognized, of course, that when hydraulic pressure is to be developed in the system by shifting either piston 81 or piston 82, it is best to close the communication through reduced portion 99 to the compensating chamber 92. Thus, by closing communication to the compensation chamber 92 as the mandrel 11 is first shifted, less travel of the mandrel is required to develop an effective hydraulic pressure.

When the bridge plug 10 is being set, it will be apparent that as the mandrel lug 70 is being shifted within its T-slot 71, means must be provided to hold the housing 12 fixed relative to the mandrel 11. Moreover, after the bridge plug 10 has been set, the housing 12 must remain anchored to the casing 21 with at least a minimum holding force whenever the mandrel 11 is not sufficiently displaced to coact with one of the pistons 81 and 82 or is shifting through its intermediate position to one of its other positions. Although conventional spring-biased drag blocks could be successfully employed for this purpose, it is preferred instead to select a spring or springs, as at 96, that have an effective spring rate to bias the compensating piston 93 with sufficient force to develop a slight hydraulic pressure in the hydraulic system.

By developing a predetermined hydraulic pressure in the system in this manner, the casing-engaging members 54 and 55 will be urged against the casing 21 with sufficient holding force to permit movement of the mandrel 11 relative to the housing 12 but without unduly limiting the positioning of the bridge plug 10. Moreover, once the casing-engaging members 54 and 55 are extended against the casing 21, it will be appreciated that subsequent shifting of the mandrel 11 will be immediately effective to develop additional hydraulic pressure since the elastomeric sleeve 53 will already be inflated.

It will, of course, be recognized that since the well bore pressure is acting against both the compensating piston 93 and elastomeric sleeve 53, the pressure in the hydraulic system will be equal to the sum of the well bore pressure plus the pressure developed by the springs 96. Thus, the spring rate of the springs 96 will directly determine the force with which the casing-engaging members 54 and 55 are urged against the casing 21. It will be further understood that the pressure developed in the hydraulic system by the action of the springs 96 against the compensating piston 93 is not sufficient to significantly foreshorten the packing elements 52. Accordingly, as the bridge plug 10 is being moved into position within the well bore 20, the anchoring means 15 will serve as drag blocks but the packing means 14 will remain substantially retracted.

Although this approach is generally successful, it has been found difficult in some instances to shift a bridge plug arranged in this manner downwardly in the well bore **20** before it has reached a depth where the tubing string **19** has sufficient weight to overcome the above-mentioned holding force. Inasmuch as the minimum required holding force may well be in the order of a few thousand pounds, it will be recognized that, in some instances, several hundreds of feet of tubing string will freely shift the bridge plug **10** downwardly.

Accordingly, the bridge plug **10** of the present invention includes means for initially removing the spring bias from the compensating piston **93** until such time that the bridge plug has reached a substantial depth in the well bore **20**. To accomplish this, the upper end of the springs **96** are preferably confined within a follower sleeve **102** having an inwardly directed shoulder **103** and a depending skirt **104** to keep the individual springs concentrically positioned. A retainer sleeve **105** having an outwardly directed shoulder **106** is extended through the springs **96**, with the shoulder **106** being normally disposed a short distance below the compensating piston **93** and engaged on top of the follower sleeve shoulder **103**. Selectively operable latch means **107** are employed to releasably secure the retainer sleeve **105** to the housing **12** for temporarily depressing the springs **96** away from the compensating piston **93**.

In the arrangement of the latch means **107** depicted in FIG. 2D, the lower end of the retainer sleeve **105** is telescoped into the upper end of a slidable locking sleeve **108**. A plurality of detents, such as balls **109** loosely mounted in the locking sleeve **108** and partially extending into a complementary annular recess **110** in the retainer sleeve **105**, releasably connect the retainer sleeve to the locking sleeve. The lower end of the locking sleeve **108** is enlarged so as to define an enclosed recess **111** between the sleeve end and the inwardly directed housing shoulder **112** thereabove. An O-ring **113** in the housing shoulder **112** fluidly seals the upper portion of the locking sleeve **108** to the housing **12**.

At the lower end **114** of the locking sleeve, a slight clearance is left to provide a predetermined annular space **115** between the sleeve **108** and housing **12** so that a viscous fluid **116**, such as grease or the like, may be confined within the enclosed space **111** therebetween. A screw **117** through the housing **12** secures the locking sleeve so that, as seen in FIG. 2, so long as the sleeve **108** is in its lowermost position, the locking balls **109** will be a short distance below an enlarged recess **118** in the inner wall of the housing shoulder **112**.

It will be appreciated, therefore, that so long as the locking balls **109** remain in the retainer sleeve recess **110**, the retainer sleeve **105** will remain connected to and be held down by the locking sleeve **108** and screw **117** to the housing **12** against the upwardly directed force of the springs **96**. Thus, so long as the springs **96** are prevented from shifting the follower sleeve **102** against the compensating piston **93**, no pressure will be developed thereby in the hydraulic system.

Accordingly, in the operation of the bridge plug **10**, the screw **117** is removed a short time before the bridge plug is introduced into the casing **21**. Once the screw **117** is removed, the springs **96** will begin urging the follower and retainer sleeves **102** and **105** upwardly. However by appropriately selecting the viscous fluid and sizing the annular space with respect to the spring rate of the springs **96**, it will require a measureable time period for a sufficient volume of the fluid **116** to be displaced through the space **115** and allow the locking sleeve **108** to shift upwardly where the balls **109** can enter the housing recess **118**. Then when the balls **109** enter the housing recess **118** the retainer sleeve **105** will be disconnected from the locking sleeve **108** and be free to move further upwardly with the follower sleeve **102** to engage the compensating piston **93**. Once the compensating piston **93** is biased by the springs **96** the hydraulic pressure developed thereby will be effective to frictionally engage the casing-engaging members **54** and **55** with the casing **21** as previously described.

When the bridge plug **10** is to be set in a well the mandrel **11** in appropriately manipulated by the tubing string **19** to shift the mandrel lug **70** into the elongated slot portion **72** of the T-slot **71**. Once the mandrel lug **70** is in the longer slot portion **72** the mandrel **11** is free to shift either upwardly or downwardly to engage either the lower piston **81** or upper piston **82** and develop a hydraulic pressure in the system for actuating the pressure-responsive anchor means **15** and packing means **14**. Thus, once the mandrel **11** is lowered or elevated the bridge plug **10** will be firmly anchored and sealingly packed-off.

It will be appreciated, however, that unless the mandrel **11** remains in one of its displaced positions, the developed hydraulic pressure will vary as the mandrel shifts relative to the housing **12**. Thus, for example, after the overshot **23** is released from the fishing neck **22**, the mandrel **11** will assume a position (within the limits established by the length of the slot portion **72**) that will be dictated by the magnitude and direction of whatever, if any, pressure differential there may be across the bridge plug **10**. Thus, with a low pressure differential, there will be a proportionately low pressure developed in the hydraulic system.

Although the effective holding force to be applied by the anchor means **15** will vary in relation to the shifting of the mandrel **11** in response to pressure differentials, it will be realized that to maintain an effective seal with the packing elements **52**, they must always be held firmly engaged against the casing **21**. Accordingly, the bridge plug **10** of the present invention includes means for selectively regulating the hydraulic pressure being applied to the packing means **14** whereby the pressure applied thereto will be maintained even though the developed pressure falls below that required to maintain the packing means sealingly engaged but still allow further increases of developed pressure to be applied to the packing means.

To accomplish this, an annular valve member **119** is slidably disposed within the housing **12** and co-rotatively secured to the mandrel **11** by a complementary longitudinal spline and groove, as at **120**. Longitudinally spaced reduced-diameter portions **121** and **122** are formed around the valve member **119** to leave an intermediate full-diameter portion **123** and provide clearance between the valve member and inner wall of the housing **12**. O-rings **124** and **125** above and below the reduced-diameter portions **121** and **122** fluidly seal the valve member **119** to the housing **12**.

The adjacent ends of the longitudinal housing passages **79** and **80** terminate in longitudinally spaced, inwardly opening annular recesses **126** and **127** formed adjacent to one another in the internal wall of the housing **12**. An O-ring **128** in the internal wall of the housing **12** between the recesses **126** and **127** is arranged to engage the intermediate full-diameter portion **123** of the valve member **119** whenever this portion is opposite the O-ring **128**.

Thus, it will be appreciated by comparison of FIG. 2 with FIG. 5 that, when the valve member **119** is so positioned that the O-ring **128** is engaged with the intermediate full-diameter portion **123** of the valve member, the reduced-diameter portions **121** and **122** will be respectively opposite the housing recesses **126** and **127** and the O-ring **128** will block direct fluid communication therebetween. Conversely, by longitudinally shifting the valve member **119** slightly with respect to the housing **12**, the intermediate full-diameter valve member portion **123** will be displaced from sealing engagement with the O-ring **128** and direct fluid communication will be established between the housing recesses **126** and **127** by way of, for example, the reduced-diameter valve member portion **121**. In either position of the valve member **119**,

the O-rings 124 and 125 at its opposite ends will straddle the housing recesses 126 and 127 and remain in sealing engagement with the inner wall of the housing 12.

It will be appreciated that the valve member 119 will selectively open and close fluid communication through the housing passages 79 and 80 depending upon its longitudinal position relative to the housing 12. Thus, with the valve member 119 displaced slightly downwardly (FIG. 2) and its intermediate full-diameter portion 123 out of sealing engagement with the O-ring 128, there will be fluid communication from the pressure-developing means 13 to the enclosed space 50 between the setting sleeves 39 and 44 of the packing means 14. On the other hand, when the valve member 119 is in the position shown in FIG. 5, fluid communication exterior of the valve member is blocked by sealing engagement of O-ring 128 with the intermediate valve member portion 123.

To control this longitudinal position of the valve member 119, an inclined slot 129 is formed in the exterior of the valve member and receives an inwardly projecting housing lug 130. Accordingly, as schematically depicted in FIG. 3, as the mandrel 11 is rotated to shift the mandrel lug 70 from the shorter slot portion 73 into the longer slot portion 72, the splined connection at 120 will rotate the valve member 119 as well. By properly arranging the inclination of the slot 129, the camming action of the housing lug 130 will shift the valve member 119 upwardly along the mandrel 11 into the position shown in FIG. 5. It will be recognized, of course, that the slots 71 and 129 must be so arranged relative to one another that the rotation of the mandrel 11 necessary to shift the lug 70 from one slot portion 72 to the other portion 73 will be sufficient to simultaneously elevate the valve member 119 to the desired position.

Thus, it will be understood that with the mandrel 11 in its intermediate position (FIG. 2), there is full communication between the pressure-responsive packing means 14 and the pressure-developing means 13. With the mandrel lug 70 in the longer slot portion 72, however, this fluid communication is blocked irrespective of the longitudinal position of the mandrel 11. To provide selective control of fluid communication to and from the packing means 14, bypass means, such as a conventional spring-biased unidirectional check valve 131 disposed in an interconnecting passage 132 through the valve member 119 between the reduced portions 121 and 122, are provided. Thus, with the check valve 131 correctly oriented, when the valve member 119 is cammed upwardly into its elevated position (FIG. 5), hydraulic fluid can move from the passage 79 to the passage 80 by way of the check valve 131 and bypass passage 132 and to the packing means 14. Flow in the reverse direction is prevented, however, by the check valve 131 as well as by the sealing engagement of the O-ring 128 with the full-diameter valve member portion 123.

Accordingly, when the bridge plug 10 is to be set, the mandrel 11 is rotated to shift the lug 70 from the shorter slot portion 73 to the longer portion 72 of the T-slot 71. As the mandrel 11 is rotated into this position, the valve member 119 is also rotated and shifted upwardly by the cooperative camming action of the housing lug 130 within the inclined slot 129 to close off unrestricted communication between the pressure-developing means 13 and packing means 14. Communication between the anchoring means 15 and pressure-developing means 13 is, of course, unaffected by this movement of the mandrel 11 and valve member 119.

Once the mandrel lug 70 is in the longer slot portion 72, the mandrel 11 is then shifted (by the tubing string 19) in either longitudinal direction relative to the housing 12 to develop a substantial hydraulic pressure sufficient for expanding the elastomeric packing elements 52 outwardly into sealing engagement with the casing 21. This increased hydraulic pressure is, of course, readily transmitted through the check valve 131. Once, however, such an increased hydraulic pressure is applied in the enclosed space 50 between the setting sleeves 39 and 44, the check valve 131 will prevent loss of this pressure through the passage 132 regardless of any subsequent decrease in developed hydraulic pressure as will occur, for example, when the mandrel 11 approaches the center of its span of travel. It will be noted that the splined connection at 120 between the mandrel 11 and valve member 119 will permit the mandrel to freely shift longitudinally without also moving the valve member. It should also be noted that should the pressure-developing means 13 subsequently develop a higher hydraulic pressure than that already trapped within the enclosed space 50, the check valve 131 will, of course, re-open to admit this higher pressure into the enclosed space.

It will be recognized that means should be provided for limiting the magnitude of hydraulic pressure retained in the enclosed space 50 between the setting sleeves 39 and 44. To accomplish this, a check valve 133 is disposed in the valve member 119 and arranged with a sufficiently strong spring 134 to open under a predetermined hydraulic pressure differential between the enclosed space 50 and pressure-developing means 13. By providing a relief passage 135 between the reduced portions 121 and 122 of the valve member 119, the relief valve 133 and spring 134 will function to relieve any excessive hydraulic pressure differential between the packing means 14 and pressure-developing means 13. Hereagain, however, this relief valve 133 will not limit the application of even extreme hydraulic pressures to the packing means 14. It will function only to relieve such extreme pressures whenever the hydraulic pressure in the pressure-developing means 13 decreases to the predetermined difference in pressures.

Turning now to the operation of the bridge plug 10 as illustrated in FIG. 2, as previously mentioned, the retaining screw 117 must be removed from the housing 12 before the bridge plug is lowered into the well. Once this screw 117 is removed, the bridge plug 10 may be lowered as the springs 96 urge the retainer sleeve 105 and locking sleeve 108 upwardly to slowly displace the grease 116 from the space 111 through the clearance 115 around the locking sleeve. Then, once the locking sleeve 108 has moved upwardly a sufficient distance for the retainer sleeve 105 to displace the locking balls 109 into the housing recess 118, the retainer sleeve is free to move on upwardly into engagement with the compensating piston 93. This, of course, will provide an adequate delay to enable a sufficient number of joints to be added to the tubing string 19 as it is progressively assembled at the surface to continue moving the bridge plug 10 against the limited frictional dragging force created upon activation of the compensating piston 93. Once the compensating springs 96 have been released, it will be appreciated that they will urge the compensating piston 93 upwardly with a predetermined force calculated to develop sufficient hydraulic pressure within the system to move the casing-engaging members 54 and 55 outwardly against the casing 21 with a desired holding force.

When the bridge plug 10 has been positioned at the depth at which it is to be set, it is halted and an upward strain is taken on the tubing string 19 as it is rotated to the right. This concerted application of tension with clockwise torque will bring the mandrel lug 70 into alignment with and then shift it through the transverse slot portion 74 into the elongated slot portion 72 of the T-slot 71. The rotation of the mandrel 11 will also simultaneously rotate the valve member 119 upwardly to close off unrestricted communication between the housing passages 79 and 80.

Once the mandrel lug 70 is shifted into the elongated slot portion 72, the mandrel 11 is free to be shifted the full limit permitted by the slot portion 72 and without shifting the valve member 119. Accordingly, by shifting the tubing string 19 either upwardly or downwardly, the pressure-developing means 13 will be employed as already

described to develop a sufficient hydraulic pressure for setting the bridge plug 10.

Thus, as the hydraulic pressure is increased, the elastomeric packing elements 52 will be foreshortened by the setting sleeves 39 and 44 and thereby expanded into sealing engagement with the casing 21. Similarly, as the hydraulic pressure is developed, the casing-engaging members 54 and 55 will be urged against the casing 21 to anchor the bridge plug 10 securely. Once the packing means 14 and anchoring means 15 are engaged, the overshot 23 is removed from the fishing neck 22. As the overshot 23 is removed, the valve member 28 is pulled upwardly thereby to close the bypass ports 29 and the central bore 27 through the mandrel 11.

It will be recognized, of course, that after the overshot 23 has been disengaged from the fishing neck 22, the mandrel 11 is free to shift longitudinally within the limits determined by the length of the longitudinal housing slot 72. Any pressure differential across the packing elements 52 will also act on the mandrel 11. Should the pressure in the well bore above the bridge plug 10 be greater than the pressure below, the pressure differential will act to shift the mandrel 11 downwardly. Downward shifting of the mandrel 11 will cause the shoulder 90 to drive the upper slidable piston member 81 downwardly, which action will result in increasing the hydraulic pressure within the system to press the casing-engaging members 54 and 55 of the anchor 15 against the well casing 21 with a force proportionately related to the pressure differential across the bridge plug 10.

Should, perchance, the pressure in the well bore below the bridge plug 10 become greater than the pressure thereabove, the mandrel 11 will be shifted upwardly. As the mandrel 11 shifts upwardly, the hydraulic pressure will be momentarily reduced as the upper piston member 81 returns to its initial position against housing shoulder 83. Moreover, as the reduced-diameter mandrel portion 99 passes upwardly relative to O-ring 89 within the lower piston 82, there will be a momentary resumption of fluid communication between the hydraulic system and the compensating chamber 92. At this point, however, the force of the compression springs 96 will be sufficient to maintain the pressure within the hydraulic system at a sufficient magnitude to maintain the wall-engaging members 54 and 55 firmly secured against the casing 21. Then, as the mandrel 11 continues to travel upwardly, the reduced-diameter mandrel portion 99 will move upwardly relative to the lower piston 82 which will then itself be shifted upwardly by the lower mandrel shoulder 91. As the mandrel 11 continues its upward movement, hydraulic pressure will again be increased within the fluid-filled hydraulic system to again urge the casing-engaging members 54 and 55 against the casing 21 with a force that is proportionately related to the pressure differential across the bridge plug 10.

It will be recalled, however, that regardless of the shifting of the mandrel 11, the valve member 119 will remain in the position shown in FIG. 5 and the check valve 131 will function to trap whatever pressure is needed to maintain the packing elements 52 firmly engaged with the casing 21. Thus, even as the mandrel 11 shifts to its central position, the packing means 14 will maintain sealing engagement with the casing 21. Moreover, should pressure differentials in the well require a greater sealing engagement with the casing 21, the check valve 131 will function to admit into the enclosed space 50 any higher hydraulic pressures developed as the mandrel 11 is shifted by such pressure differentials.

To release the bridge plug 10, it is necessary only to re-engage the fishing neck 23. The equalizing valve member 28 is again shifted downwardly to bring ports 32 therein into registry with mandrel ports 29. With the fluid pressure equalized across the retrievable bridge plug 10, the mandrel 11 is shifted to its intermediate position and torqued to the left to return the mandrel lug 70 through the slot portion 74 into the shorter slot portion 73.

It will be appreciated that as the mandrel lug 70 is being rotated through the slot portion 74, the valve member 119 will be cammed downwardly to re-establish direct communication between the enclosed space 50 and the balance of the hydraulic system. Moreover, with the mandrel 11 again in its intermediate "neutral" position, the compensating chamber 92 will also again be in communication (by way of reduced mandrel portion 99) with the hydraulic system. Thus, the pressure in the system will now drop to what it was before the bridge plug 10 was set and the packing means 14 will return to their retracted position.

It will be understood, of course, that once it is released and as the retrievable bridge plug 10 is being shifted, the compensating springs 96 will remain engaged with the compensating piston 93. Thus, the wall-engaging members 54 and 55 will still be held agains the casing 21 with the predetermined holding force as previously described. This, however, will present no problem in shifting the bridge plug 10 in either direction inasmuch as the tubing string 19 can be pulled upwardly with more than sufficient force to overcome this predetermined holding force and the weight of the tubing string at this depth will still be sufficient to move the bridge plug downwardly. Thus, should it be desired to position the bridge plug 10 at a different depth without first removing it from the well bore, it is only necessary to halt the bridge plug at the desired position and repeat the above-described setting operation. Then, when it is desired to finally retrieve the bridge plug, it is necessary only to repeat the above-described retrieving operation and remove the bridge plug 10 from the well bore.

Turning now to FIG. 6, an alternate embodiment is shown of pressure-responsive latch means 150 for temporarily depressing the compensating springs 96 out of engagement with the compensating piston 151. In this arrangement, the hydrostatic pressure of well fluids at a predetermined depth is employed to release the springs 96. To accomplish this, the retainer sleeve 152 is slidably disposed within the lower end of the housing 12' and releasably secured thereto by a frangible shear member, such as a pin 153 or the like, to hold an upper shoulder 154 of the follower sleeve 155 a short distance below the compensating piston 93'. The compression springs 96 are mounted around the retainer sleeve 152 within the follower sleeve 155 and confined between an upwardly directed housing shoulder 156 and a downwardly directed shoulder on the follower sleeve. An annular piston member 157 having a reduced-diameter upper portion 158 and an enlarged-diameter lower portion 159 is slidably disposed within the housing 12' below the shear member 153. O-rings 160 and 161, respectively, around the enlarged and reduced portions 159 and 158 of the release piston 157 are spaced from one another and fluidly seal the piston relative to the housing 12' to define an enclosed, sealed space 162 therebetween.

To release the retainer sleeve 152, the stepped release piston 157 immdiately below the shear pin 153 is appropriately arranged to move upwardly and into engagement with the lower end of the retainer sleeve in response to the hydrostatic pressure of fluids in the well bore. It will be appreciated that as the bridge plug 10' is assembled at the surface, the space 162 between the O-rings 160 and 161 will be at atmospheric pressure. Thus, as the hydrostatic pressure increases during the descent of the bridge plug 10, it will act upon the effective cross-sectional area between O-rings 160 and 161 to urge the release piston 157 upwardly against the lower end of the retainer sleeve 152 with a force proportionately related to the hydrostatic pressure. Then, whenever the bridge plug 10' has reached a depth at which the hydrostatic pressure is sufficient to enable the release piston 157 to shear the pin 153, the retainer sleeve 152 will be released from

the housing 12' and be biased upwardly by the springs 96 into engagement with the compensating piston 93'. Once the retainer sleeve 152 is released, the operation of the bridge plug 10' will be as already described. It should also be noted that the same hydrostatic release principle could be employed with the embodiment of FIG. 2 to shift the locking balls 109 into the housing recess 118.

Accordingly, it will be appreciated that the present invention provides a unique control for a hydraulically actuated well tool. By providing a well tool with selectively operable valve means arranged in accordance with the present invention, the tool is given substantially more flexibility in that the mandrel is movable in one manner to operate the valve means; but, in another position, the mandrel is free to move without also actuating the valve means. Thus, by employing the valve means of the present invention with a hydraulically actuated well tool having one or more separately movable elements, selective actuation of various elements is now possible.

While a particular embodiment of the present invention has been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects; and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

I claim:

1. A well tool sized and adapted for reception in a well bore comprising: a tubular housing; a mandrel movably disposed within said housing; means coupling said mandrel to said housing for securing said mandrel against substantial longitudinal shifting in one angular position of said mandrel relative to said housing and for freeing said mandrel for longitudinal shifting between spaced positions in other angular positions of said mandrel relative to said housing; pressure-responsive means movably mounted on said housing and movable relative thereto in response to a hydraulic pressure; pressure-developing means including piston means fluidly sealed within said housing and slidable in response to shifting of said mandrel toward one of said spaced positions for developing an increased hydraulic pressure; control means including first, second and third passage means interconnecting said pressure-developing means and pressure-responsive means, first valve means in said first passage means adapted to admit hydraulic pressure into said pressure-responsive means but prevent release of hydraulic pressure therefrom, second valve means in said second passage means for selectively limiting hydraulic pressure in said pressure-responsive means to a predetermined maximum differential above the pressure in said pressure-developing means, and third valve means in said third passage means for selectively opening and closing said third passage means; and actuating means between said mandrel and third valve means for opening said third valve means in response to movement of said mandrel toward said one angular position and for closing said third valve means in response to movement of said mandrel toward said other angular positions.

2. The well tool of claim 1 further including second piston means fluidly sealed within said housing and slidable in response to shifting of said mandrel toward another of said spaced positions for developing an increased hydraulic pressure.

3. The well tool of claim 2 wherein said mandrel is intermediate of said spaced positions whenever it is in said one angular position, said piston means are annular piston members respectively slidably disposed around and fluidly sealed to said mandrel, and further including first and second spaced opposed means on said mandrel adapted to engage and shift their associated piston members as said mandrel respectively moves toward either of said spaced positions.

4. The well tool of claim 3 wherein said third valve means includes a body movably disposed within said housing between said pressure-developing means and said pressure-responsive means, first sealing means on said housing fluidly sealing said housing relative to said body, second sealing means on said body fluidly sealing said body relative to said housing, one of said sealing means being spaced sealing members to define said third passage means in the annular space between said body and said housing and the other of said sealing means being in said annular space between said spaced sealing members, said first passage means opening into said third passage means on opposite sides of said other sealing means.

5. The well tool of claim 4 wherein said pressure-responsive means are expansible packing means adapted for expansion into sealing engagement within a well bore upon application of hydraulic pressure thereto.

6. The well tool of claim 5 wherein said actuating means include a transverse cam member between said housing and body and secured to one of the last-named members, an inclined slot receiving said cam member in the other of said last-named members and arranged to shift said body longitudinally as said mandrel is moved between said angular positions, and means co-rotatively securing said body to said mandrel.

7. The well tool of claim 1 wherein said third valve means includes a body movably disposed within said housing between said pressure-developing means and said pressure-responsive means, first sealing means on said housing fluidly sealing said housing relative to said body, second sealing means on said body fluidly sealing said body relative to said housing, one of said sealing means being spaced sealing members to define said third passage means in the annular space between said body and said housing and the other of said sealing means being in said annular space between said spaced sealing members, said first passage means opening into said third passage means on opposite sides of said other sealing means.

8. The well tool of claim 7 wherein said body is telescoped around said mandrel and further including second piston means fluidly sealed within said housing and slidable in response to shifting of said mandrel toward another of said spaced positions for developing an increased hydraulic pressure.

9. The well tool of claim 8 wherein said actuating means include a transverse cam member between said housing and body and secured to one of the last-named members, and inclined slot receiving said cam member in the other of said last-named members and arranged to shift said body longitudinally as said mandrel is moved between said angular positions, and means co-rotatively securing said body to said mandrel.

10. The well tool of claim 9 wherein said second passage means opens into said third passage means on opposite sides of said other sealing means.

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