United States Patent

[11] 3,577,782

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[54] **WELL LOGGING TOOL FOR MAKING MULTIPLE PRESSURE TESTS AND FOR BOTTOM HOLE SAMPLING**
13 Claims, 15 Drawing Figs.

[52] **U.S. Cl.** **73/155,** 73/421
[51] **Int. Cl.** **E21b 49/00**
[50] **Field of Search** 73/155, 421, 152; 166/264

[56] **References Cited**
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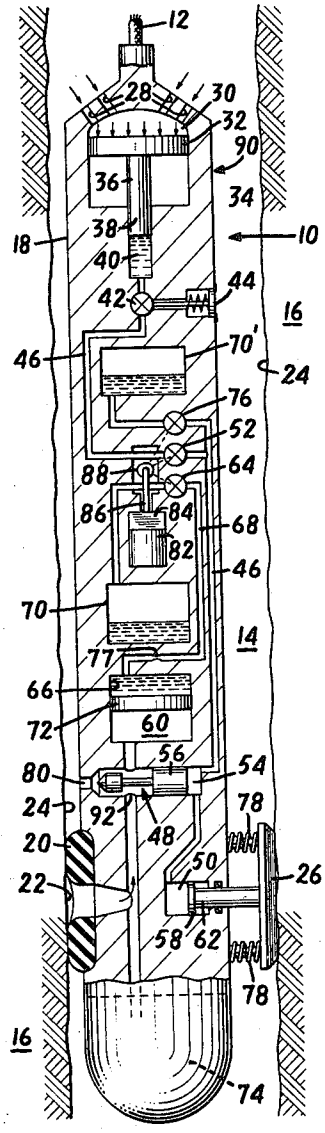
Primary Examiner—Jerry W. Myracle
Attorney—Brumbaugh, Graves, Donohue and Raymond

ABSTRACT: Apparatus is provided for obtaining a plurality of readings with respect to fluids in formations traversed by a well bore. The apparatus includes a housing, annular sealing means for sealing off an area of the wall of the well bore from fluid within the well bore, and formation-fluid-receiving sample chamber means within the housing in communication with sealed-off area of the wall. Gauge means operatively associated with the chamber means is provided for obtaining a reading with respect to fluid within the chamber means, and motive means is provided for bringing the chamber means into cooperation with discrete samples of formation fluid collected at spaced-apart locations in the well bore. In this way, a plurality of readings with respect to fluid in the formations is obtainable in a single traverse of the well bore by the apparatus.



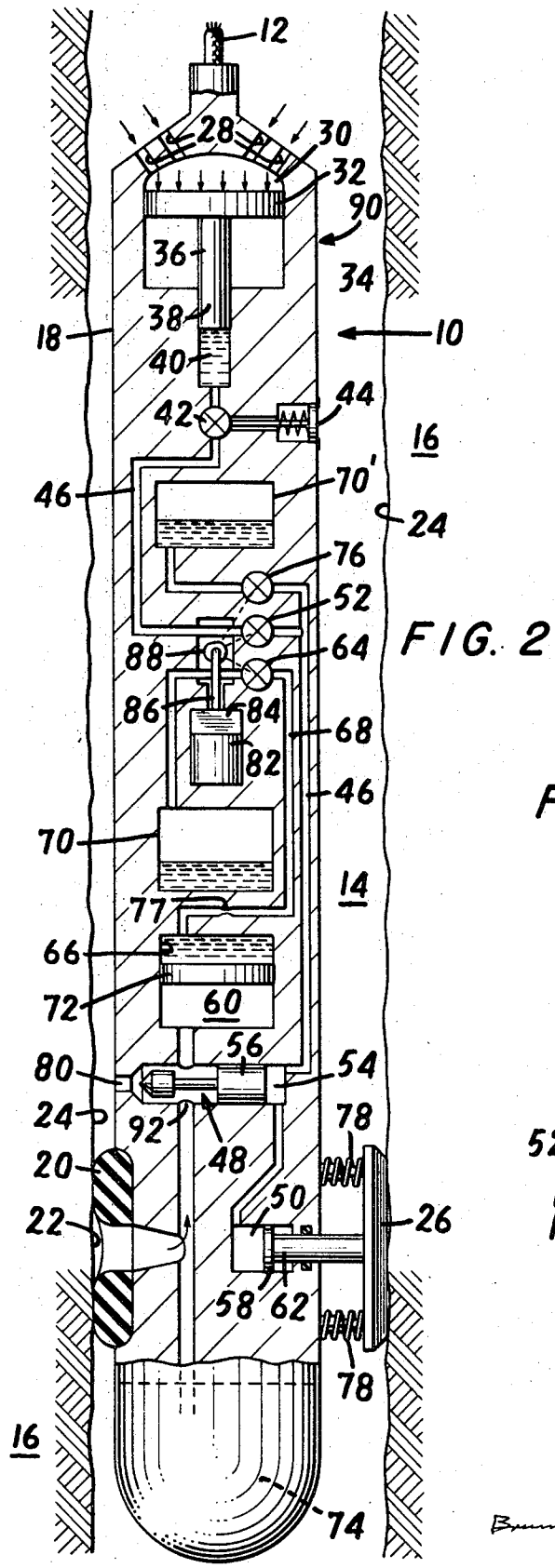


FIG. 2

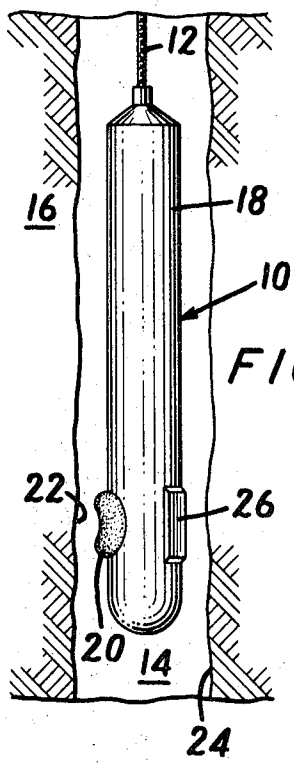
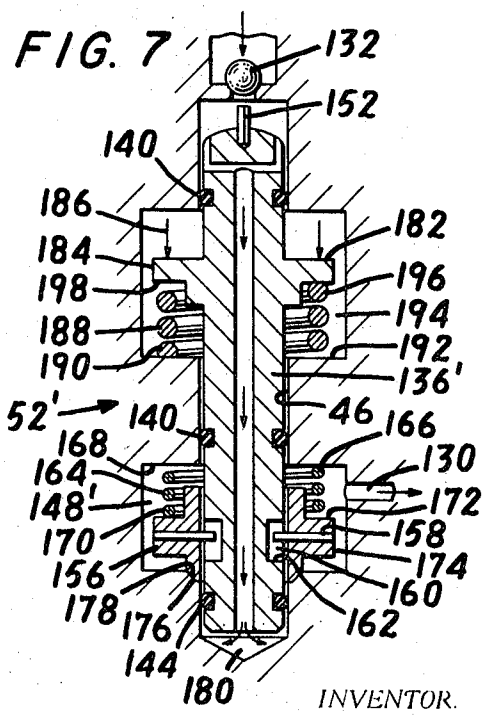


FIG. 1

FIG. 7



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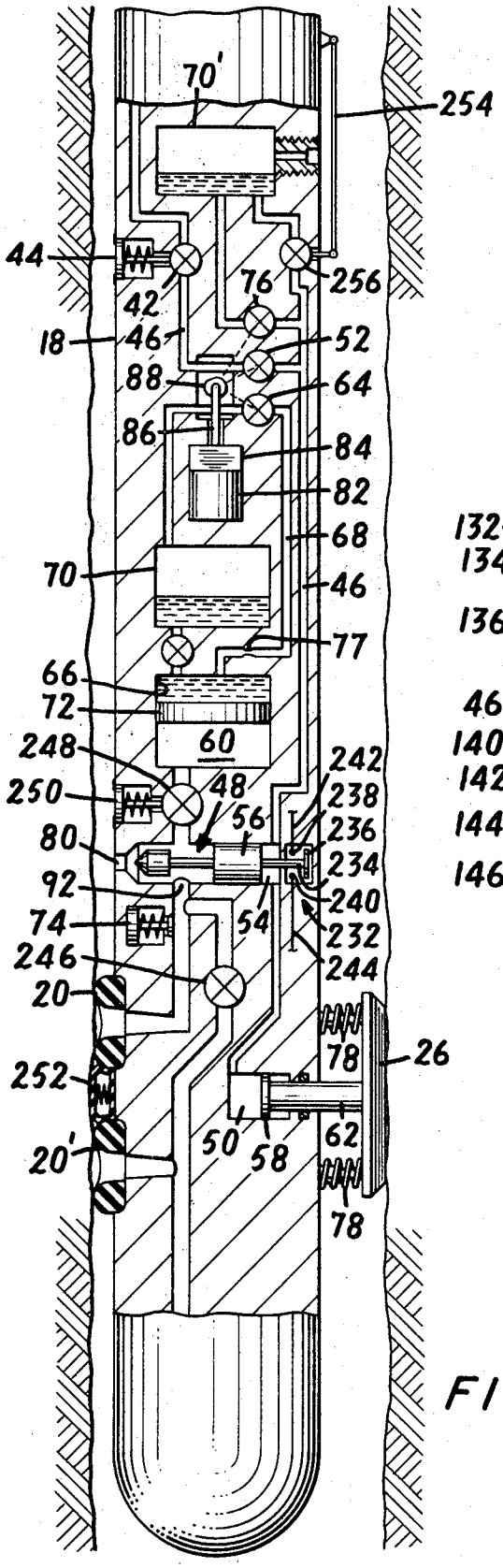

FIG. 3

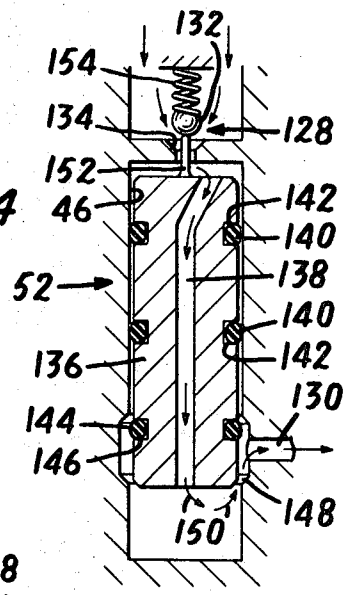

FIG. 4

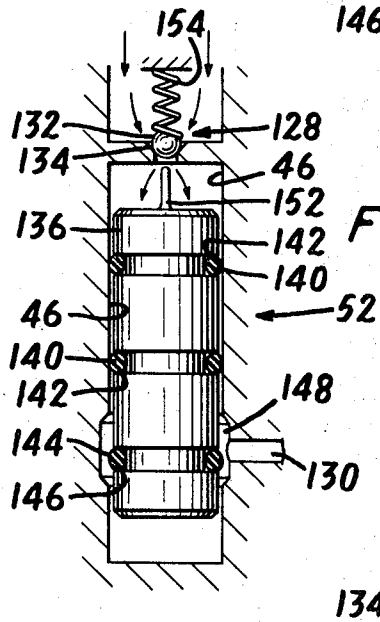

FIG. 5

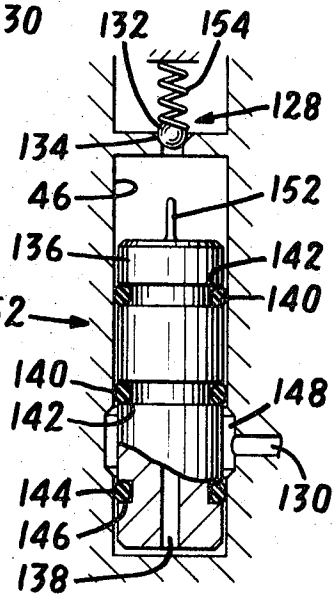

FIG. 6

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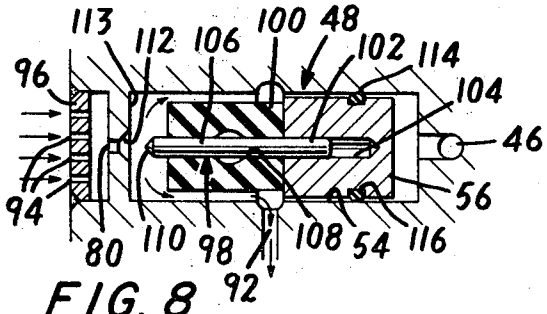

FIG. 8

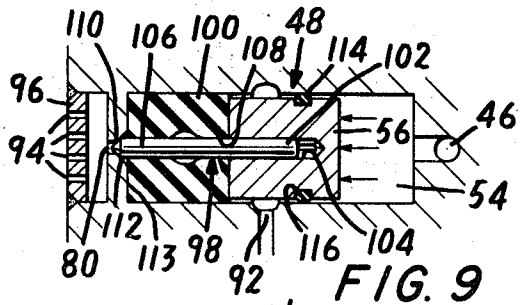

FIG. 9

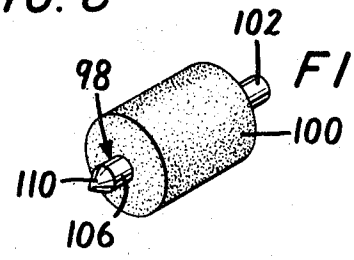

FIG. 10

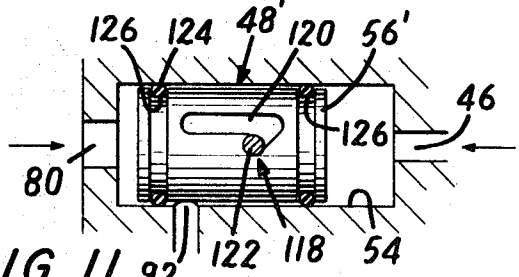

FIG. 11

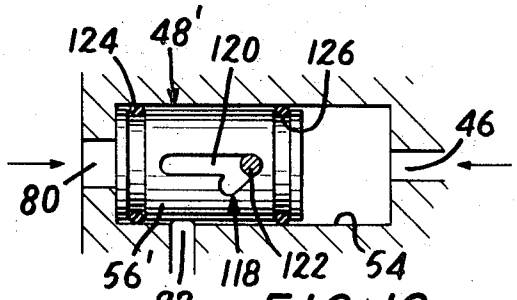

FIG. 12

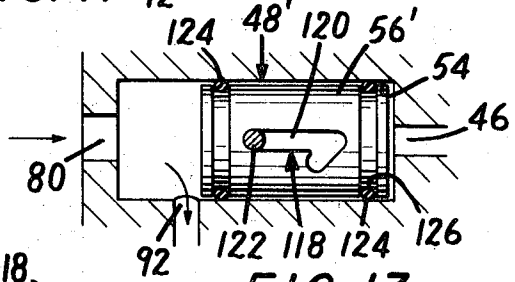

FIG. 13

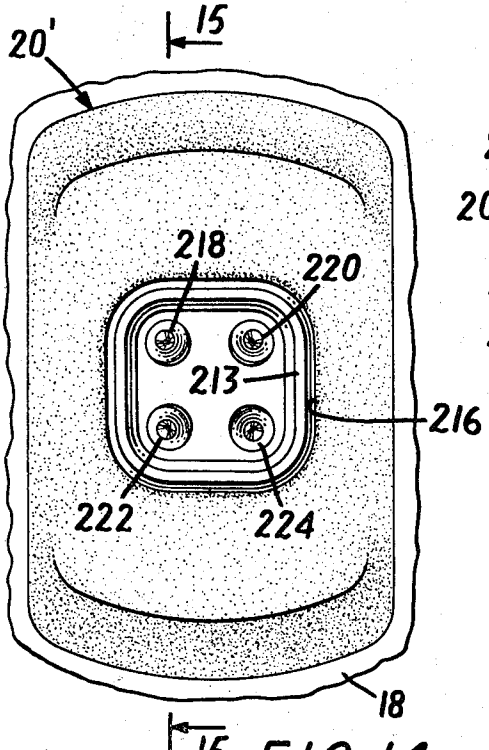

FIG. 14

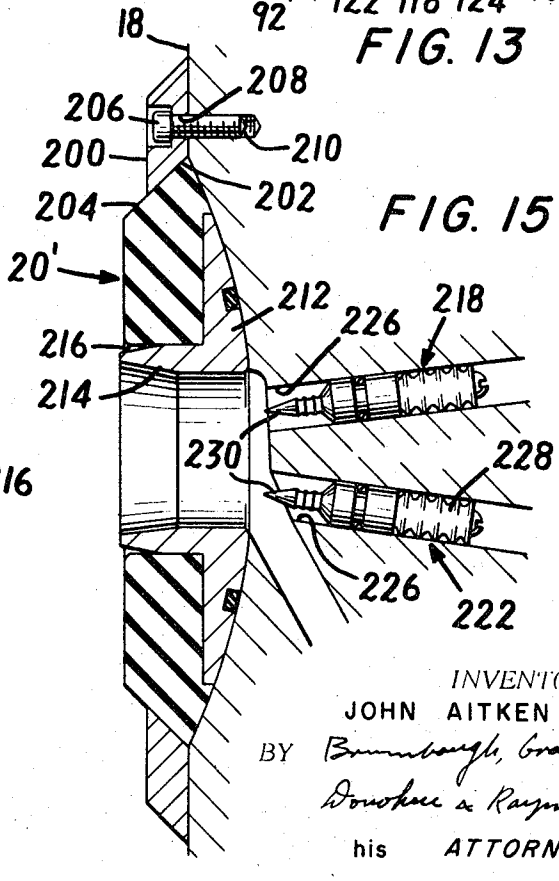

FIG. 15

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WELL LOGGING TOOL FOR MAKING MULTIPLE PRESSURE TESTS AND FOR BOTTOM HOLE SAMPLING

The apparatus includes pressure means responsive to the pressure of the fluid within the well bore for boosting the pressure of an operating fluid within the housing to a pressure greater than the pressure of the well bore fluid at the depth of the apparatus, and pressure-equalizing valve means communicating with the annular sealing means for facilitating the maintenance of pressures on opposite sides of the annular sealing means that are unequal or equal, as may be necessary during a particular phase of a well logging operating.

Explosive means is provided for perforating the wall of the well bore, the explosive means being detonated by operation of the pressure-equalizing valve means.

A composite valve is also provided including a first part which is highly abrasion and extrusion resistant and a second part which forms a leakproof seal.

CROSS-REFERENCE TO RELATED APPLICATION

The present invention is in part an improvement of an invention disclosed and claimed in a copending application of Maurice P. Lebourg and Roger Q. Fields, Ser. No. 790,321, filed Jan. 10, 1969, for "Tool to take Multiple Formation Fluid Pressures."

BACKGROUND OF THE INVENTION

This invention relates to well surveying and, in particular, to novel and highly effective apparatus facilitating the obtaining of a plurality of readings with respect to fluids in formations traversed by a well bore in a single traverse of the well bore. The invention also relates to novel valve means particularly adapted for use in well surveying but also having a wide variety of other uses.

The copending application identified above also discloses methods and apparatus facilitating the obtaining of a plurality of readings with respect to fluids in formations traversed by a well bore in a single traverse of the well bore, and claims generic to that aspect of the present invention are presented in that application.

The art of gathering information regarding earth formations is developed to a high state, as evidenced by U.S. Pat. No. 3,011,554, to Desbrandes et al., U.S. Pat. No. 3,104,712 to Whitten and U.S. Pat. No. 3,261,402, and U.S. Pat. No. 3,329,208 to Voetter. There remains a need, however, for improved means for obtaining a plurality of readings with respect to fluids in earth formations. There is, in particular, a need for improved valve means adapted to facilitate the operation of well logging tools.

It is possible, of course, to obtain a plurality of readings with respect to connate fluids in earth formations traversed by a well bore by the expedient of lowering a conventional measuring tool or instrument a plurality of times in the well bore, each time obtaining information with regard to fluids in a formation at a selected depth in the well bore. This process is time consuming and expensive, however, because of the delay occasioned each time it is necessary to withdraw the tool from the well bore following a given reading, prepare the tool to take a subsequent readings, and lower the tool into the well bore to the depth selected for the subsequent reading.

Withdrawal of the tool between successive readings is the conventional practice, because of the limited capacity of conventional tools to receive fluid samples for pressure or other measurements.

Many conventional valves are of course available for performing the various flow-control functions characterizing the operation of well logging devices, but there is a need to improve the conventional valves to make them more reliable and efficient while keeping their cost to a minimum.

SUMMARY OF THE INVENTION

An object of the present invention is to provide improved apparatus for obtaining a plurality of readings with respect to fluids in formations traversed by a well bore. Another object of the invention is to reduce the cost and time involved in the surveying of a well. A further object of the invention is to provide rugged and compact apparatus that is inexpensive to manufacture and repair and that can obtain as many readings as may be desired in a single traverse of a well bore. Still another object of the invention is to provide apparatus particularly adapted for bottom hole sampling in a well. A further object of the invention is to provide valve means for controlling the flow of an operating fluid and also for controlling the flow, within the tool housing, of a fluid in which the tool is immersed, in order to facilitate the accomplishment of the various functions which the tool is adapted to perform.

The foregoing and other objects of the invention are accomplished, in representative apparatus for obtaining a plurality of readings with respect to fluids in formations traversed by a well bore, by the provision of apparatus including a housing, annular sealing means mounted on the housing for sealing off an area of the wall of the well bore from fluid within the well bore, formation-fluid-receiving chamber means within the housing in communication with the sealed-off area of the wall, gauge means operatively associated with the chamber means for obtaining a reading with respect to formation fluid within the chamber means, and motive means for bringing the chamber means into cooperation with discrete samples of formation fluid collected at spaced-apart locations within the well bore, whereby a plurality of readings with respect to fluid in the formations is obtainable in a single traverse of the well bore by the apparatus.

In accordance with the invention, the motive means comprises pressure means within the housing responsive to the pressure of the fluid within the well bore for boosting the pressure of an operating fluid within the housing to a pressure greater than the pressure of the well bore fluid and movable positioning means mounted on the housing, the positioning means when set forcing the annular sealing means against the wall of the well bore. First conduit means is provided in the housing communicating with the positioning means, and first valve means is provided in the first conduit means. Dump chamber means is also provided in the housing, together with second conduit means communicating with the dump chamber means and operatively associated with the sample chamber means. Second valve means is in the second conduit means, and the first valve means, when opened, permits operating fluid to set the positioning means, thereby forcing the annular sealing means against the wall of the well bore.

When the second valve means is opened, it permits expansion of the sample chamber means and a consequent reduction of pressure and collection of a formation fluid sample therein. When the second valve means is closed, it prevents further expansion of the sample chamber means and permits the obtaining of a reading by the gauge means with respect to the sample.

The objects of the invention are attained also by the provision of a composite valve comprising conduit means formed with an enlarged portion, an inlet, an outlet, a first valve member movable in the conduit means, a valve seat therefor, the first valve member and valve seat being made of an abrasion-resistant and extrusion-resistant material, and a second valve member movable in the conduit means and partly within the enlarged portion and having first and second spaced-apart peripheral resilient sealing means. The second valve member is formed with a fluid flow passage therethrough, the first resilient sealing means preventing fluid flow between the second valve member and the conduit means. The second valve member is selectively movable between a position *a* in which the second resilient sealing means is in the fluid flow path between the passage and the enlarged portion to prevent fluid flow through the passage and out the outlet and a position *b* in which at least some of the enlarged portion is in the fluid flow path between the passage and the second resilient sealing means to permit fluid flow through the passage and out the outlet. The second valve member is formed with engaging means for engaging the first valve member and removing it

from the valve seat when the second valve member is in position *b*, and the second valve member moves from position *a* to position *b* before unseating of the first valve member and from position *b* to position *a* after seating of the first valve member.

The objects of the invention are also attained by the provision of an equalizing valve in a fluid-flow passage communicating with the interior of the annular sealing means and including a cylinder and a piston slidable therein, the cylinder communicating at one end with operating fluid for operating the positioning means and at the other end with fluid in the well bore. The piston, in response to a pressure of the operating fluid sufficient to set the positioning means, slides to seal off the interior of the annular sealing means from the well bore fluid, and, in response to reduction in the pressure of the operating fluid sufficient to permit retraction of the positioning means, slides to open communication between the interior of the annular sealing means and the well bore fluid. In this way, the pressure on opposite sides of the annular sealing means is selectively made unequal to facilitate collection of samples and then is equalized to facilitate withdrawal of the annular sealing means from the well bore wall.

The objects of the invention are also attained by the provision of means for dumping operating fluid into a dump chamber in response to the uncoupling of the well tool from means suspending the tool in the well bore, the dumping of the operating fluid facilitating retraction of the positioning means.

The objects of the invention are also attained by the rigging of a well surveying tool for monocable operation. This is accomplished by means including a novel valve assembly and a control means therefor effective to operate the valve assembly in a prescribed sequence.

BRIEF DESCRIPTION OF THE DRAWING

An understanding of additional aspects of the invention may be gained from a consideration of the following detailed description of representative embodiments of apparatus constructed in accordance with the invention and of the accompanying FIGS. in the drawing, in which:

FIG. **1** is a diagrammatic view of apparatus constructed in accordance with the invention suspended in a well bore;

FIG. **2** is an elevational view, partly in section, of a first representative embodiment of apparatus constructed in accordance with the invention;

FIG. **3** is an elevational view, partly in section, of a second representative embodiment of apparatus constructed in accordance with the invention;

FIGS. **4**, **5**, and **6** are elevational views, partly in section, of a first representative embodiment of a composite valve constructed in accordance with the invention, showing the valve in three different positions;

FIG. **7** is an elevational view, partly in section, of a preferred embodiment of the valve of FIGS. **4**—**6**;

FIGS. **8** and **9** are elevational views, partly in section, of a representative embodiment of an equalizing valve constructed in accordance with the invention, showing the valve in two different positions;

FIG. **10** is a perspective view of a component of the valve of FIGS. **8** and **9**;

FIGS. **11**—**13** are elevational views, partly in section, of a second representative embodiment of an equalizing valve constructed in accordance with the invention, showing the valve in three different positions;

FIG. **14** is an elevational view of annular sealing means and perforating means suitable for use in accordance with the invention; and

FIG. **15** is a sectional view, taken along the line **15**–**15** of FIG. **14** and looking in the direction of the arrows.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** shows a tool or device **10** constructed in accordance with the invention suspended by a cable **12** in a well bore **14** traversing earth formations **16**. The tool **10** includes a housing **18** on which are annular sealing means **20** adapted to seal off an area **22** of a well bore **24** and positioning means including a wall-engaging member such as a shoe or pad **26** adapted to be moved outwardly with respect to the housing **18** against the wall **24** of the well bore **14** and, by reaction, force the annular sealing means **20** against the area **22** to be sealed off from fluid in the well bore **14**.

The cable **12** runs to means (not shown) at the head of the well bore **14** for raising and lowering the tool **10** in the well bore **14**. In accordance with the invention, the annular sealing means **20** may be forced successively against a plurality of areas of the well bore wall **24** for collecting a plurality of samples from the formation **16** without withdrawing the tool **10** from the well bore **14** between the taking of successive samples.

FIG. **2** shows in detail the structure of the tool **10**. The housing **18** is formed with mud-entry apertures **28** providing entry into a mud cylinder **30** of the fluid in which the tool **10** is immersed. A mud piston **32** is slidable in the mud-cylinder **30**, there being suitable sealing means between the periphery of the mud piston **32** and the wall **34** of the mud cylinder **30** so that fluid cannot flow from one side of the mud piston **32** to the other.

A ram extension **36** rigidly connected to the mud piston **32** has a high-pressure piston portion **38** fitting within a high-pressure cylinder **40** constituting an oil reservoir. A pressure regulator valve **42** including a pressure sensing portion **44** exposed to the exterior of the housing **18** regulates the pressure of the oil or other fluid in the conduit means **46** through which the operating fluid is supplied to an equalizing valve **48** and a cylinder **50** operating the movable positioning means or backup shoe **26**.

A first valve **52** in the conduit means **46** controls the flow of operating fluid through the conduit means **46**. When the valve **52** is opened, operating fluid at high pressure flows through the conduit means **46** and into a cylinder **54** and the cylinder **50**. Within the cylinder **54**, the operating fluid forces a piston **56** to the left as seen in FIG. **2** and forces a piston **58** to the right as seen in FIG. **2**.

The forcing of the piston **56** to the left closes the equalizing valve **48** to isolate the interior of the annular sealing meaning **20** and, therefore, to isolate a sample collection chamber **60** from the fluid in which the tool **10** is immersed.

The forcing of the piston **58** to the right also forces a ram extension **62** and the positioning means **26** to the right against the wall **24** of the well bore **14**. By reaction, the annular sealing means **20** is forced against a selected area **22** of the wall **24** of the well bore **14**.

A second valve **64** is then opened to permit fluid in a cylinder **66** to flow through a line or conduit **68**, through the valve **64**, and into dump chamber means **70**. A free piston **72** separates the lower and upper portions of the cylinder **66**. The lower portion of the cylinder **66** constitutes the collection chamber **60**. The pressure within the collection chamber **60** is initially equal to the pressure of the fluid in which the tool **10** is immersed.

The dump chamber means **70** is at a pressure considerably lower than the pressure of the fluid in which the tool **10** is immersed, and the opening of the valve **64** therefore results in a flow of fluid from the upper portion of the chamber **66**, through the line **68** and the valve **64**, and into the dump chamber means **70**. Such flow reduces the pressure of the sample chamber **60** to a value lower than the pressure of the fluid in the formation **16**, and the fluid in the formation **16** flows through the annular sealing means **20** for sampling. A conventional gauge **74** communicates with the sample chamber **60** to measure a characteristic of interest of the collected fluid sample. For example, the pressure of the collected fluid sample may be measured. Any suitable conventional pressure gauge may be used for this purpose. The gauge may either make a record on a recording medium in the tool **10**, which can be read when the tool is recovered, or may indicate a reading at a remote location, such as the head of the well.

During the reading of the pressure, the second valve **64** is of course closed to allow the pressure within the sample chamber **60** to approach the pressure of the fluid in the formation **16**.

At the conclusion of the test, the first valve **52** is closed and a third valve **76** is opened to dump the operating fluid from the cylinders **50** and **54** and the portion of the line **46** downstream of the valve **52** into dump chamber means **70'**. For convenience, the dump chamber means **70** and **70'** are illustrated as separate, but they may be connected and at the same pressure.

The flow of fluid through the line **68** is retarded by a choke **77** to prevent the fluid from flowing too swiftly into the dump chamber means **70**.

Upon the dumping of the fluid from the high-pressure line **46** into the dump chamber means **70'**, the pressure within the cylinders **50** and **54** is very much reduced, and the pressure of the fluid in which the tool **10** is immersed moves the piston **56** to the right as seen in FIG. **2** and the piston **58** to the left as seen in the same FIG. The movement of the latter piston is facilitated by coil springs **78** which are under tension and which extend between the housing **18** and the positioning means **26**. The retraction of the positioning means **26** facilitates withdrawal of the annular sealing means **20** from the wall **24** of the well bore **14**. Such withdrawal is further facilitated by the movement of the piston **56** to the right, which uncovers a port **80** in the housing **18** and reestablishes communication between the interior of the annular sealing means **20** and the sample chamber **60** on the one hand and the fluid in which the tool **10** is immersed on the other.

As noted above, the sequence of operation of the first, second, and third valves **52**, **64** and **76**, respectively, is as follows: (1) the first valve **52** opens; (2) the second valve **64** opens; (3) the second valve **74** closes; and (4) the first valve **52** closes and the third valve **76** opens. Operation of the valves in this sequence is attained by the provision of an electric motor **82** driving reduction gearing **84** which in turn drives a camshaft **86** on which cam means **88** is mounted for controlling the operation of the respective valves.

Because the diameter of the high-pressure piston **38** is less than that of the lower pressure piston **32**, the pressure within the high-pressure cylinder **40** is greater than the pressure within the mud cylinder **30**, and the pistons **32** and **38** and cylinders **30** and **40** therefore constitute a piston-cylinder assembly functioning a pressure multiplier **90**. The pressure multiplier **90** is part of a motive means for bringing the annular sealing means **20** into contact with a selected area of the wall **24** of the well bore **14**.

FIGS. **8—13** show in detail two preferred embodiments of the equalizing valve constructed in accordance with the invention.

The valve **48** shown in FIGS. **8** and **9** includes the piston **56** slidable within the cylinder **54** for selectively closing and opening the inlet **80** in response to high and low pressure, respectively, of the operating fluid in the conduit means **46**. The cylinder **54** is formed with an outlet **92**, shown also in FIG. **2**, through which fluid communication between the inlet **80**, the outlet **92**, and the space within the annular sealing means **20** (FIG. **2**) is established when the valve **48** is in the position shown in FIG. **8**. In this position of the valve, therefore, the fluid in which the tool **10** is immersed enters through apertures **94** in a screen **96**, passes through the inlet **80**, the portion of the cylinder **54** to the left (as seen in FIG. **8**) of the piston **56**, through the outlet **92**, and to the interior of the annular sealing means to equalize the pressure on opposite sides of the annular sealing means and to facilitate withdrawal thereof from the wall **24** of the well bore **14**.

The tool is then moved to another selected area of the well bore, and the annular sealing means **20** is forced against the wall **24** of the well bore **14** at this area by setting of the positioning means in the manner described in connection with FIG. **2**. As noted in the description of FIG. **2**, the setting of the positioning means **26** is accompanied by the closing of the equalizing valve **48**. The closed position of the equalizing valve **48** is illustrated in FIG. **9**. In this position, the piston **56** is forced to the left by operating fluid such as oil under high pressure admitted through the conduit means **46**.

A plug assembly including a pin **98** and a plug **100** formed of elastomeric material seals off the inlet **80**. Specifically, the pin **98** has a portion **102** mounted in a bore **104** formed in the piston **56** and a projecting portion **106** extending through a bore **108** in the plug **100**. The pin **98** also has a projecting tip **110** which is conical or otherwise beveled to fit tightly in a valve seat **112** which defines the inlet **80**.

When the equalizing valve **48** is closed, the tip **110** seats firmly in the valve seat **112** so that the elastomeric material forming the plug **100** cannot be extruded into the inlet **80**. The elastomeric material, being substantially incompressible, expands radially and contracts axially in response to the pressure exerted by the operating fluid on the piston **56**. Thus, in the open condition of the valve **48**, the plug **100** has a diameter smaller than the diameter of the cylinder **54**. On the other hand, in the closed condition of the valve **48**, the elastomeric material of which the plug **100** is formed expands radially until its diameter is substantially equal to the diameter of the cylinder **54**. At the same time, the plug **100** is forced firmly against the end wall **113** of the cylinder **54**. The elastomeric plug **100** is thus forced tightly against the wall of the cylinder **54** surrounding the inlet **80**.

At the same time, the sliding of the piston **56** to close the inlet **80** also closes the outlet **92**. The piston **56** is metallic, as is the pin **98**, so that the elastomeric material of the plug **100** is likewise prevented from being extruded into the outlet **92**.

An O-ring seal **114** in a peripheral groove **116** formed in the piston **56** tightly engages the wall of the cylinder **54** and prevents the passage of operating fluid or fluid from the well bore **14** from one side of the piston **56** to the other.

FIGS. **11—13** show an alternate embodiment of the valve illustrated in FIGS. **8—10**. The equalizing valve **48'** is movable between three positions. Cam and cam follower means **118** operatively associated with the cylinder **54** and piston **56'** facilitates movement from the first position to second position and from the second position to the third position.

The cam and cam follower means **118** may comprise, for example, a J-shaped slot **120** formed in the piston **56'** and a spring-loaded pin **122** projecting from the wall of the cylinder **54**. Alternatively, the slot may be formed in the wall of the cylinder and the projecting pin may be mounted on the piston.

In the first position, illustrated in FIG. **11**, the pin **22** is at the extremity of the short arm of the J **120** as the tool **10** is immersed in a well bore fluid. The pressure of the fluid forces the piston **56** to the right (as seen in FIG. **11**), there being little or no oil pressure in the conduit means **46**. O-ring seals **124** and **126** similar to the ring O-ring seals **114** are mounted on the piston **56'** near opposite ends thereof to prevent leakage of well bore fluid and operating fluid, respectively, around the seals and out the outlet **92**.

In the second position, illustrated in FIG. **12**, operating fluid under high pressure is introduced through the conduit means **46** to force the cylinder **56'** to the left (as seen in FIG. **12**). The cooperation of the cam **120** and cam follower **122** produces a rotation of the piston **56'** as the cam follower **122** moves from the extremity of the short arm of the J to the vertex of the J. This rotation of the piston **56'** aligns the cam follower **122** with the long arm of the J. The second position is maintained during the testing. As noted above, the high-pressure oil in the conduit **46** sets the positioning means **26** so that the annular sealing means **20** is forced tightly against a selected area of the wall **24** of the well bore **14** to seal off such area from the fluid in the well bore **14**. In the position of FIG. **2**, the piston **56'** seals off the inlet **80** from the outlet **92**, so that there is no communication between the fluid in the well bore and the interior of the annular sealing means.

FIG. **13** illustrates the third position, which results upon the lowering of the pressure of the operating fluid in the conduit means **46**. The pressure of the fluid in the well bore **14** forces the piston **56'** to the right (as seen in FIG. **13**), such move-

ment being permitted because of the previously-mentioned alignement between the cam follower **122** and the long arm of the J cam **120**. This movement of the piston **56'** establishes a fluid flow path between the inlet **80** and the outlet **92** and permits well bore fluid to flow into the interior of the annular sealing means **20** and reduce or eliminate the pressure differential across the annular sealing means **20**, thereby facilitating withdrawal of the annular sealing means **20** from the wall **24** of the well bore **14**.

FIGS. **4—7** show two exemplary embodiments of a valve which has many uses but which is particularly adapted for use as the valve **52** of FIG. **2**. In the valve **52**, and in other valves which must open and close repeatedly under high-pressure differentials, it is necessary to protect against erosion and extrusion of the sealing elements. FIGS. **4—6** disclose a first exemplary embodiment of a valve well adapted to operate successfully during a large number of cycles under high-pressure differentials. The valve is a composite valve comprising conduit means **46**, an inlet **128**, and an outlet **130**. A first valve member **132**, which may be a metal ball of small diameter, cooperates with a metallic valve seat **134** shaped complementally to the valve member **132**.

Because the valve member **132** and the valve seat **134** are metallic, there is minimum erosion of these elements during periods when the valve is open and during periods when it is being opened or being closed. Also, because the valve member **132** and valve seat **134** are small, the circumferential leakage path between the valve member **132** and valve seat **134** is short, and, in the closed position of the valve, leakage is reduced to a minimum, notwithstanding that the parts are metallic.

A second valve member **136** is also provided in accordance with the invention, and the valve member **36** is formed with a fluid passage **138** therethrough. The second valve member **136** is also provided with first resilient sealing means **140** such as a pair of O-rings fitting within annular grooves **142** extending peripherally of the second valve member **36**. In addition, the second valve member **36** is provided with second resilient sealing means such as an O-ring **144** mounted within an annular groove **146** extending peripherally of the second valve member **136**. While the first resilient sealing means is **140** is illustrated as comprising two O-rings and the second resilient sealing means **144** is illustrated as comprising one O-ring, the number of O-rings or other elements constituting the resilient sealing means can be varied within wide limits. It is important, however, that the sealing means **140** on the one hand would be spaced apart from the sealing means **144** on the other.

The first resilient sealing means **140** prevents fluid flow between the second valve member **136** and the conduit means **46**. The second valve member **136** is selectively movable between a position *a* in which the second resilient sealing means **144** is between the passage **138** and an enlarged portion **148** of the conduit means **46** (FIG. **6**) and a position *b* in which at least some of the enlarged portion **148** is between the passage **138** and the second resilient sealing means **144**. (FIG. **4**).

In position *a*, the second resilient sealing means **144** prevents fluid flow through the passage **138** and out the outlet **130**. In position *b*, fluid flow is permitted through the passage **138** and out the outlet **130**, as indicated by arrows **150**.

The second valve member **136** is formed with engaging means **152** for engaging the first valve member **132** and removing it from the valve seat **134** when the second valve member **136** is in position *b*, as shown in FIG. **4**. The second valve member **136** moves from position *a* to position *b* before the unseating of the first valve member **132** and from position *b* to position *a* after the seating of the first valve member **132**. In this way, the abrasion-resistant and extrusion-resistant first valve section of the composite valve **52** protects the second valve section including the resilient sealing means during the critical moments when the second valve member **136** is in the process of opening or closing. As a result, the resilient sealing means of the second valve member **136** is not subjected to high-speed flow during opening and closing, even though the valve **52** considered as a whole operates under extremely high-pressure differentials.

The valve **42** of course includes suitable means for moving the second valve member **36** and a conventional device such as a spring or other biasing means **154** to facilitate the seating of the first valve member **132**.

FIG. **7** shows a preferred embodiment of a valve adapted to operate under extremely high differential pressures. The valve **52'** shown in FIG. **7** is similar to the valve **52** shown in FIG. **4—6** but differs therefrom significantly in having a protecting sleeve **156** in the enlarged portion **148'** of the conduit means **46**. The protecting sleeve **156** fits closely about the second valve member **136'**. The second valve member **136'** is slidable with respect to the sleeve **156** a limited distance. Engaging means including lifting pins **158** engageable in an elongated circumferential slot **160** is provided permitting the second valve member **136'** to slide a limited distance with respect to the protecting sleeve **156**. The lifting pins **158** engage the bottom wall **162** of the slot **160** following limited movement of the second valve member **156** from position *a* towards position *b*. The protecting sleeve **156** moves with the second valve member **136'** during the remainder of the movement of the second valve member **136'** from position *a* to position *b*.

When the lifting pins **158** and bottom wall **162** of the slot **160** are thus engaged, the second annular resilient sealing means **144** is within the protecting sleeve **156** and protected from extrusion thereby.

When the valve member **136'** returns from position *b* to position *a* the protecting sleeve **156** is restored to the position illustrated in FIG. **7** by biasing means such as a compression coil spring **164** gearing at one end **166** against the upper wall **168** of the enlarged portion **158'** and at the other end **170** against the upper surface **172** of a flange **174** formed on the protecting sleeve **156**.

The protecting sleeve **156** is formed with a beveled lower portion **176** fitting against a complementally beveled seat **178** so that, in the position of the valve illustrated in FIG. **7**, an additional seal is provided preventing the leakage of fluid. In the open position of the valve, the fluid is permitted to flow as shown by the arrows **180** out the outlet **130**.

The valve closing force is applied to the upper surface **182** of the flange **184** formed on the second valve member **36'** and acts in the direction indicated by the arrows **186**. A valve-opening biasing means such as a compression coil spring **188** bears at one end **190** against the lower surface **192** of an additional enlarged portion **194** and at its upper end **196** against the lower surface **198** of the flange **184**.

The cam profile for operating the valve provides a slow closing during which the opening spring **188** is compressed and a rapid opening during which the opening spring **188** becomes relatively extended.

The second valve member **136'** together with the resilient sealing means **140** and **144** constitutes a positive seal element in equilibrium, there being equal fluid pressure on opposite sides thereof. Moreover, it is sandwiched between two metal valves of minimum cross section. The valve is therefore exceptionally well adapted for service under conditions of extreme pressure such as the condition to which the valve **52** (FIG. **2**) is subjected. The valve **52'** may also, of course, be used as the valve **76** and the valve **64** illustrated in FIG. **2**. Other environments in which valve **52'** serve especially well will readily occur to those skilled in the art.

FIGS. **14** and **15** show in detail in structure of annular sealing means **20'** suitable for use in accordance with the invention and also show perforation means for perforating formations of low permeability. The annular sealing means **20'** may be made of any suitable seal-forming material, such as an elastomeric material. A retainer **200** includes a beveled surface **202** adapted to bear against a complementally beveled surface **204** of the sealing means **20'**. The retainer is held by suitable fastening means such as bolts **206** passed slidably through apertures **208** in the retainer **200** and into apertures

210 formed in the housing 18. A rigid insert 212 includes an annular flange 214 supporting the inner periphery 216 of the sealing means 20' and preventing extrusion thereof during the withdrawal of formation fluid.

Four bullets 218, 220, 222 and 224 are provided for penetrating formations of low permeability. The bullets are mounted in cylinders 226 angles to aim the bullets toward a common point a short distance in front of the annular sealing means 20'. Each bullet includes a change 228 and a projectile 230. The change 2228 is detonated electrically by closing of contact means 232 (FIG. 3) connected to the equalizing valve 48. Firing may be selective, so that only one bullet is fired each time the positioning means 26 is set and the annular means 20' is forced against the wall 24 of the well bore.

FIG. 3 shows the structure and operation of the means for detonating the charges. A ram extension 234 connected to the piston 56 includes a contact plate 236 in spaced-apart relation to contacts 238 and 240. When the piston 256 is forced to the left (as seen in FIG. 3) by high-pressure oil in the cylinder 54, the ram extension 243 is also forced to the left, and the contact plate 236 closes with the contacts 238 and 240. The contact 238 is connected to a lead 242 which extends to a source of electrical power, and the contact 248 is connected to a lead 244 which extends to the charges 228 or to a stepping switch adapted to connect the lead 244 to the charges 228 in succession.

The embodiment of FIG. 3 includes not only the annular sealing means 20 but also the annular sealing means 20' associated with the bullets 218, 220, 222 and 224. A valve 246 isolates the space within the annular sealing means 20' from the sample chamber 60 while a determination is made whether the formation is sufficiently permeable to collect a fluid sample through the annular sealing means 20. If it is not, then the stepping switch (not shown) may be actuated to pass current through the lead 242, the contact 238, the plate 236, the contact 240, and the lead 244 to detonate one of the charges, say the charge 218. This perforates the formation to permit the flow of fluid from the formation, if any is present. The valve 246 is opened to permit such collected fluid to flow into the sample chamber 60.

An automatic seal valve 248 prevents contamination of the sample. The seal valve 248 has an element 250 communicating with the exterior of the housing 18 and responsive to the pressure of the fluid in which the tool 10 is immersed. The automatic seal valve 248 prevents contamination of the sample, whether the sample is collected through the annular sealing means 20 or through the annular sealing means 20'.

In close proximity to the annular sealing means 20 and 20', for example between them, a microlog bumper 252 may be mounted. The microlog bumper 252 includes electrodes for measuring the resistivity of a substance with which they are in contact and facilitates accurate positioning of the tool 10. Moreover, the associated circuitry may be used in cased holes to measure the resistivity of fluids being sampled to determine whether or not cement should be squeezed.

The apparatus of FIG. 3 also includes a mechanical dump valve rod 254 for opening a dump valve 256 discharging operating fluid from the line 46 into the dump chamber means 70'. The mechanical dump valve rod 254 opens the dump valve 256 when a shear pin is pulled to release the tool 10 mechanically. This results in dumping of the operating fluid into the dump chamber 70' instead of into the mud column, thereby insuring positive closure of the tool 10, and in retraction of the shoe 26 and opening of the equalizing valve 48 to permit withdrawal of the tool 10 from the selected area of the wall 24 of the well bore.

The tool of FIG. 3 is particularly well adapted for wildcat or offshore use where equipment is left at the location on a rental basis. The cost of such equipment is only a small fraction of the cost of conventional equipment for performing the necessary surveying. The unit has no expendable parts, and reloading consists only of recovering the sample, pushing the mud piston up, and servicing the gun block or connecting a spare. The tool need never be disconnected from the cable. A sample within a foot of the bottom of the hole may be taken as soon as a show is observed in the cuttings, and testing may be done before extensive filtrate contamination of the formation has taken place.

Thus, there is provided in accordance with the invention novel and highly effective apparatus facilitating the taking of a number of samples of fluids in formations traversed by a well bore. In accordance with the invention formation testing can be made profitable in many locations where the investment in fixed assets and supplies is too high in accordance with conventional practice to justify operations. The tool is well adapted for housing auxiliary gauges and various cement and chemical treating squeeze devices. Only one cable conductor is required to open and close the valves 52, 64, and 76 in proper sequence, therefore permitting monocable operation.

Many modifications of the representative embodiments of the invention described above will readily occur to those skilled in the art. For example, an additional sample collection chamber may be included in the tool. Further, a snorkel may be mounted within the annular sealing means 20 and extended into very soft formations to prevent an initial surge of fluid into the chamber. Accordingly, the invention is to be construed as including all of the modifications thereof within the scope of the appended claims.

I claim:

1. In apparatus for obtaining a plurality of readings with respect to fluids in formations traversed by a well bore, said apparatus including a housing, annular sealing means mounted on said housing for sealing off an area of the wall of said well bore from fluid within said well bore, expansible formation-fluid-sample-receiving chamber means within said housing in communication with said sealed-off area of said wall, gauge means operatively connected to said sample chamber means for obtaining a reading with respect to formation fluid within said sample chamber means, and motive means for bringing said sample chamber means into cooperation with discrete samples of formation fluid collected at spaced-apart locations in said well bore, whereby a plurality of readings with respect to fluid in said formations is obtainable in a single traverse of said well bore by said apparatus, the improvement wherein said motive means comprises pressure multiplier means within said housing responsive to the pressure of said fluid within said well bore for boosting the pressure of an operating fluid within said housing to a pressure greater than the pressure of said well bore fluid at the depth of said apparatus, positioning means mounted on said housing and movable between a retracted position and a set position, first conduit means in said housing communicating with said pressure multiplier means and with said positioning means, first valve means in said first conduit means, dump chamber means in said housing, second conduit means in said housing communicating with said dump chamber means and operatively connected to said sample chamber means, and second valve means in said second conduit means, said first valve means when open permitting operating fluid to set said positioning means, thereby forcing said annular sealing means against the wall of said well bore, and said second valve means being movable between open and closed positions and when open permitting expansion of said sample chamber means and a consequent reduction of pressure therein and collection of a formation fluid sample therein and when closed preventing further expansion of said sample chamber means and permitting the obtaining of a reading by said gauge means with respect to said sample.

2. Apparatus according to claim 1 further comprising pressure-equalizing valve means in said housing communicating with said first conduit means and with the exterior of aid housing and dump valve means in said first conduit means, said first conduit means communicating through said dump valve means with said dump chamber means, said pressure-equalizing valve means being closed during setting of said positioning means by pressure of operating fluid in said first conduit

means and being opened by pressure of fluid on said well bore following opening of said dump valve means, said pressure-equalizing valve means communicating with said annular sealing means and when open admitting fluid from said well bore to the interior of said annular sealing means, thereby reducing the pressure differential across said annular sealing means and facilitating withdrawal of said annular sealing means from the wall of said well bore.

3. In a tool for lowering into a well bore to collect samples of fluids in formations traversed by said well bore, said tool having annular sealing means and positioning means mounted thereon and means exerting pressure on an operating fluid for setting said positioning means to force said annular sealing means against the wall of said well bore, thereby sealing off an area of the wall of said well bore from fluid in said well bore, the improvement comprising port means connecting said well bore and the interior of said annular sealing means, an equalizing valve including a cylinder and a piston slidable therein, said cylinder communicating at one end with operating fluid for operating said positioning means and at the other end with said port means and fluid in said well bore, said piston, in response to a pressure of said operating fluid sufficient to set said positioning means, sliding to close off said port means and seal off the interior of said annular sealing means from said well bore fluid, and, in response to reduction in the pressure of said operating fluid sufficient to permit retraction of said positioning means, sliding to open said port means and establish communication between the interior of said annular sealing means and said well bore fluid, whereby the pressure on opposite sides of said annular sealing means is selectively made unequal to facilitate collection of said samples and then equalized to facilitate withdrawal of said annular sealing means from said well bore wall.

4. A valve according to claim 3 further comprising explosive means mounted on said tool operatively connected to said annular sealing means for perforating a low-permeability area sealed off by said annular sealing means and contact means operatively connected to said piston and mounted to cause detonation of said explosive means upon said sealing off by said piston of the interior of said annular sealing means from said well bore fluid.

5. In the combination of a fluid-sample-collecting tool, suspension means operatively connected thereto for lowering said tool into a well bore to collect samples of fluids in formations traversed by said well bore, said tool having annular sealing means and positioning means mounted thereon and means employing an operating fluid to set said positioning means to force said annular sealing means against the wall of said well bore, thereby sealing off an area of the wall of said well bore from fluid in said well bore, the improvement comprising dump chamber means in said tool operatively connected to said positioning means and valve means operatively connected to said coupling means and responsive to uncoupling thereof for dumping said operating fluid into said dump chamber means to facilitate retraction of said positioning means.

6. In a tool for lowering into a well bore traversing earth formations and having sample chamber means for collecting formation fluid samples therein, annular sealing means thereon communicating with said sample chamber means and mounted for sealing off an area of the wall of said well bore from fluid within said well bore, positioning means thereon for forcing said annular sealing means against the wall of said well bore, a source of an operating fluid under pressure, and dump chamber means therein for said operating fluid, the combination of a first valve for admitting said operating fluid under pressure to set said positioning means, thereby forcing said annular sealing means against the wall of said well bore, a second valve for connecting said sample chamber means to said dump chamber means to facilitate reduction of pressure in said sample chamber means and collection of a formation fluid sample therein, and a third valve for dumping said operating fluid into said dump chamber means, thereby facilitating retraction of said positioning means, and valve-operating means for first opening said first valve, then opening said second valve, then closing said second valve, and finally closing said first valve and opening said third valve.

7. The combination according to claim 6 in which said valve-operating means comprises cam means mounted on a single camshaft.

8. Formation-testing apparatus adapted for obtaining a plurality of successive samples of connate fluids in earth formations traversed by a well bore and comprising: a housing adapted for suspension in a well bore; sample-receiving chamber means on said housing adapted for receiving a plurality of successive samples of connate fluids; sample-admitting means on said housing including annular sealing means adapted for sealing engagement with a well bore wall for obtaining samples of connate fluids from earth formations adjacent thereto; pressure-responsive positioning means on said housing including a wall-engaging member adapted for movement into and out of engagement with a well bore wall for selectively moving said annular sealing means into and out of sealing engagement with a well bore wall; pressure-multiplier means on said housing including piston means responsive to the hydrostatic pressure of well bore fluids operatively arranged in piston chamber means and adapted for movement therein from a first position toward a plurality of spaced positions for successively displacing a hydraulic fluid from said piston chamber means at a higher pressure than the hydrostatic pressure of well bore fluids acting on said piston means each time said piston means moves to one of said spaced positions; first means adapted for selectively extending said wall-engaging member against a well bore wall and including an inlet conduit coupling said piston chamber means and said pressure-responsive positioning means, and first valve means in said inlet conduit adapted for movement between open and closed positions for selectively admitting a hydraulic fluid from said piston chamber means to said positioning means; second means adapted for selectively discharging samples of connate fluids entering said sample-admitting means into said sample-receiving chamber means and including a sample conduit coupling said sample-admitting means and said sample-receiving chamber means, and second valve means in said sample conduit and adapted for movement between open and closed positions for selectively controlling admission of connate fluids into said sample-receiving chamber means; third means adapted for selectively retracting said wall-engaging member from a well bore wall and including an outlet conduit coupled to said pressure-responsive positioning means, and third valve means in said outlet conduit and adapted for movement between open and closed positions for selectively discharging hydraulic fluids from said positioning means; and valve-actuating means on said housing operatively engaged with said first, second and third valve means and adapted for repetitively opening and closing said valve means in a selected sequence in response to selected commands from the surface.

9. The formation-testing apparatus of claim 8 further including: pressure-measuring means on said housing in pressure communication with said sample-receiving chamber means and adapted for providing measurements representative of the fluid pressure of connate fluids admitted to said sample-receiving chamber means.

10. The formation-testing apparatus of claim 9 further including recording means operatively coupled to said pressure-measuring means and adapted for recording measurements produced by said pressure-measuring means.

11. The formation-testing apparatus of claim 10 wherein said recording means is on said housing.

12. The formation-testing apparatus of claim 8 wherein said valve-actuating means includes: motor means on said housing and adapted for movement between successive positions in response to said commands; cam means operatively engaged with said first, second and third valve means and adapted for respectively opening and closing said valve means upon movement of said cam means between first, second and third operating positions; and means operatively connecting said

motor means and said cam means and adapted for repetitively moving said cam means to each of said operating positions in sequence upon each movement of said motor means.

13. The formation-testing apparatus of claim 12 wherein said cam means includes means operatively arranged for opening only said first valve means in said first operating position of said cam means for opening said second valve means and retaining said first valve means open in said second operating position of said cam means, and for closing said first and second valve means and opening said third valve means in said third operating position of said cam means.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,577,782 Dated May 4, 1971

Inventor(s) John Aitken

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

ABSTRACT, line 6, after "with" insert --the--; Col. 1, line 11, "operating" should be --operation--; Col. 5, line 34, "74" should be --64--; Col. 5, line 69, after "tool" insert --10--; Col. 7, line 2, "alignement" should be --alignment--; Col. 8, line 10, "Fig. " should be --Figs.--(second occurrence); Col. 8, line 33, "gearing" should be --bearing--; Col. 9, line 9, "change" should be --charge--; Col. 9, line 10, "change" should be --charge--; Col. 9, line 10, "2228" should be --228--; Col. 9, line 13, after "annular" insert --sealing--.

Signed and sealed this 14th day of December 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Acting Commissioner of Patents