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Claycomb

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[54] DATA-SIGNALING APPARATUS FOR WELL DRILLING TOOLS

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[73] Assignee: **Schlumberger Technology Corporation,** New York, N.Y.

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[52] **U.S. Cl.** ..... **340/18 LD, 340/18 NCS**

[51] **Int. Cl.** **G01v 1/14**

[58] **Field of Search** ..... 340/18 LD, 18 NCS

[56] **References Cited**

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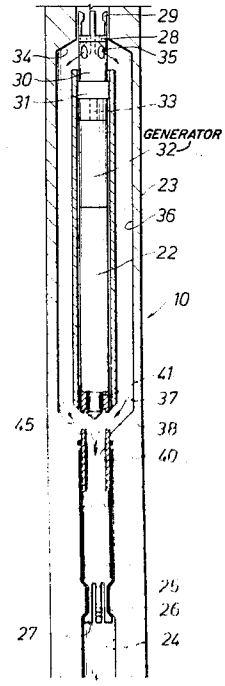
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[57] **ABSTRACT**

In the preferred embodiments of the invention disclosed herein, a well tool having new and improved data-signaling apparatus and carrying a drill bit on its lower end is dependently coupled from a drill string and lowered into a borehole being excavated. During the drilling operation, measurements are successively made of selected borehole conditions, formation properties, or the like, which are converted by the data-signaling apparatus into coded electrical signal for repetitively initiating the operation of a valve of unique design operatively arranged on the tool to be selectively actuated by the drilling fluid interrupting the flow of the drilling fluid being circulated through the drill string. In this manner, the valve functions to produce a series of encoded pressure pulses in the drilling fluid which are representative of the measurements being obtained. These pressure pulses are transmitted through the drilling fluid to the surface where they are sensed and converted into meaningful indications of the measurements.

12 Claims, 10 Drawing Figures



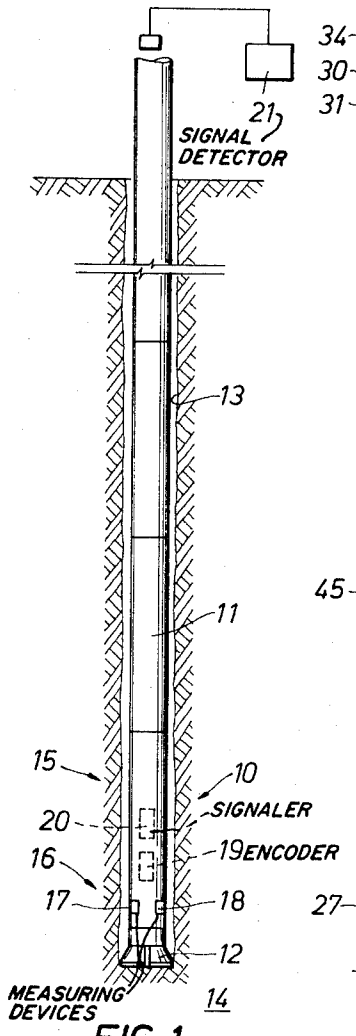


FIG. 1

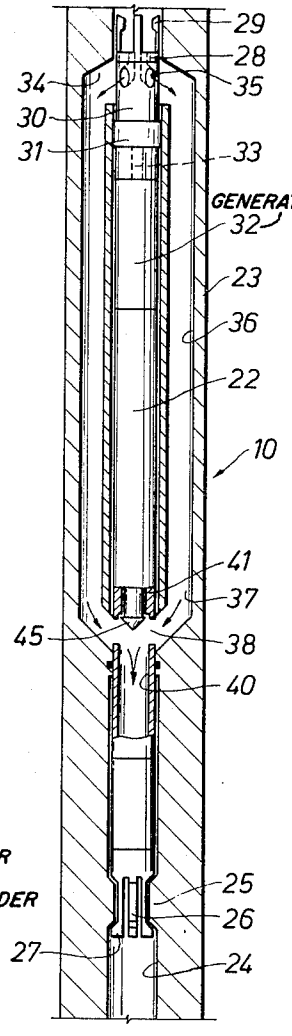


FIG. 2

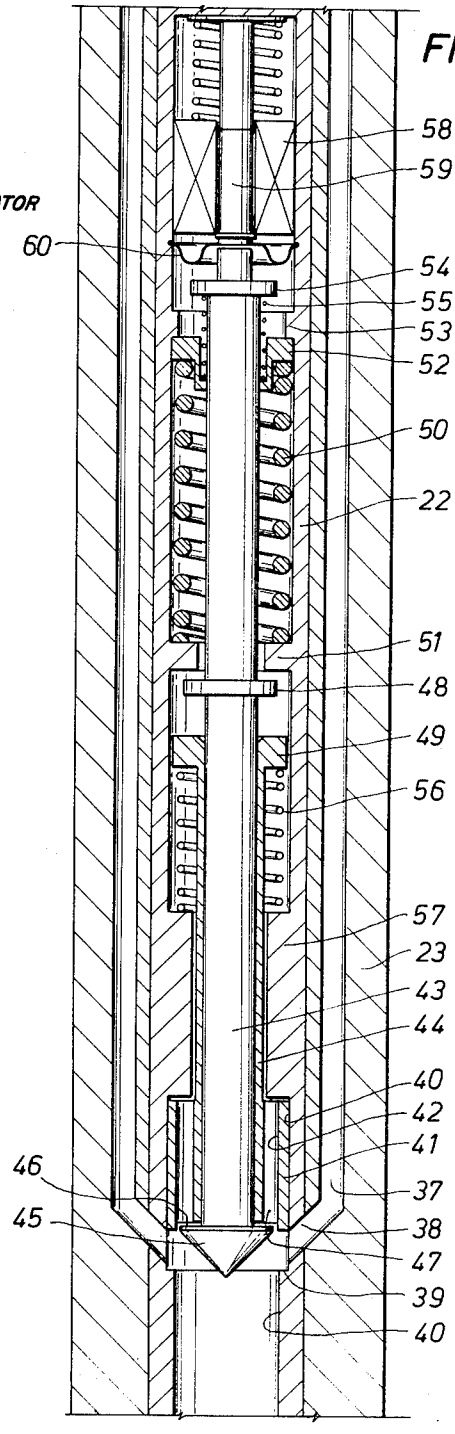


FIG. 3

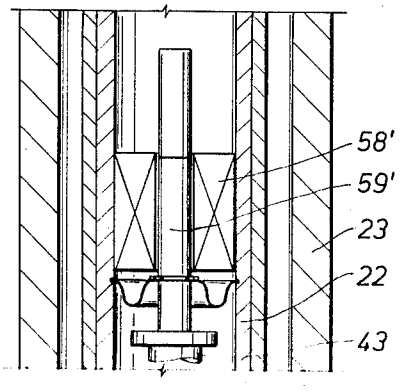


FIG. 6

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FIG.4

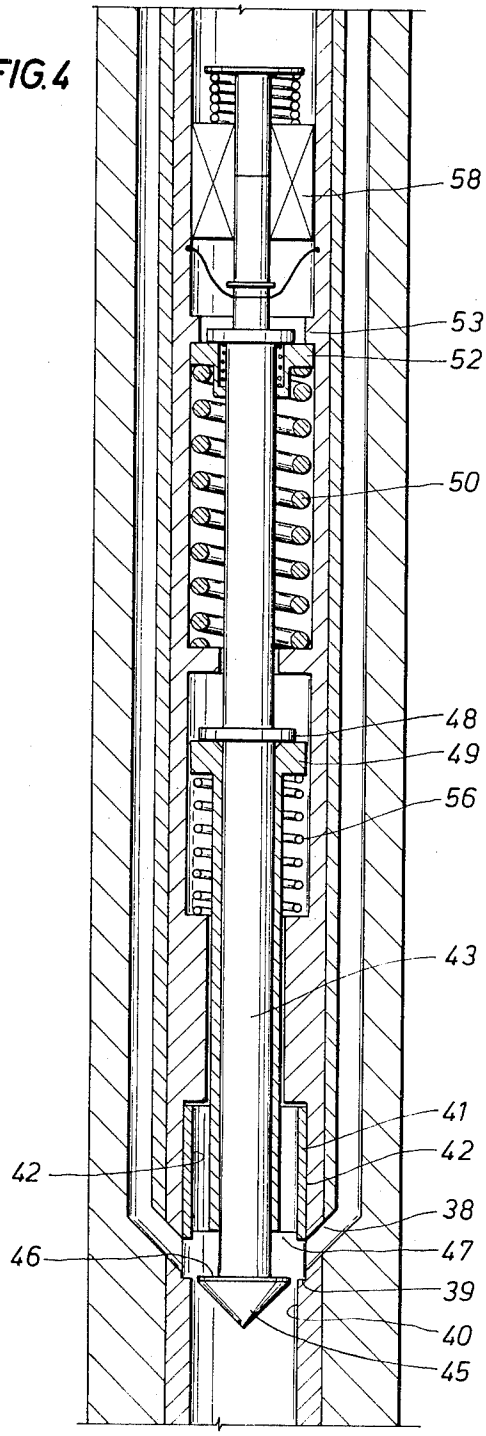
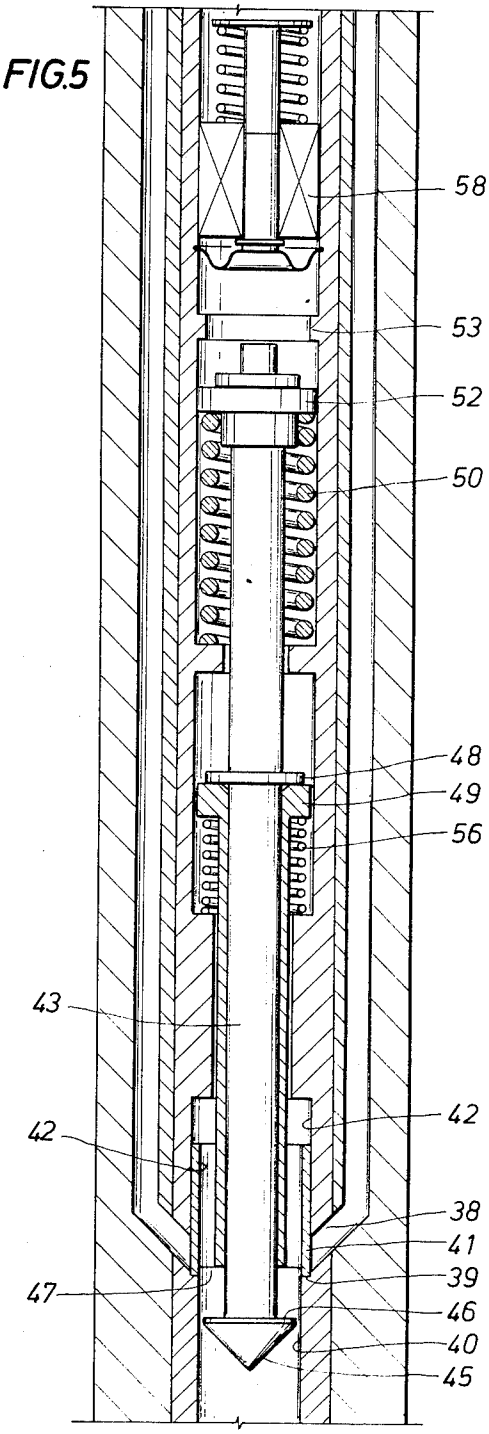


FIG.5



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FIG. 7

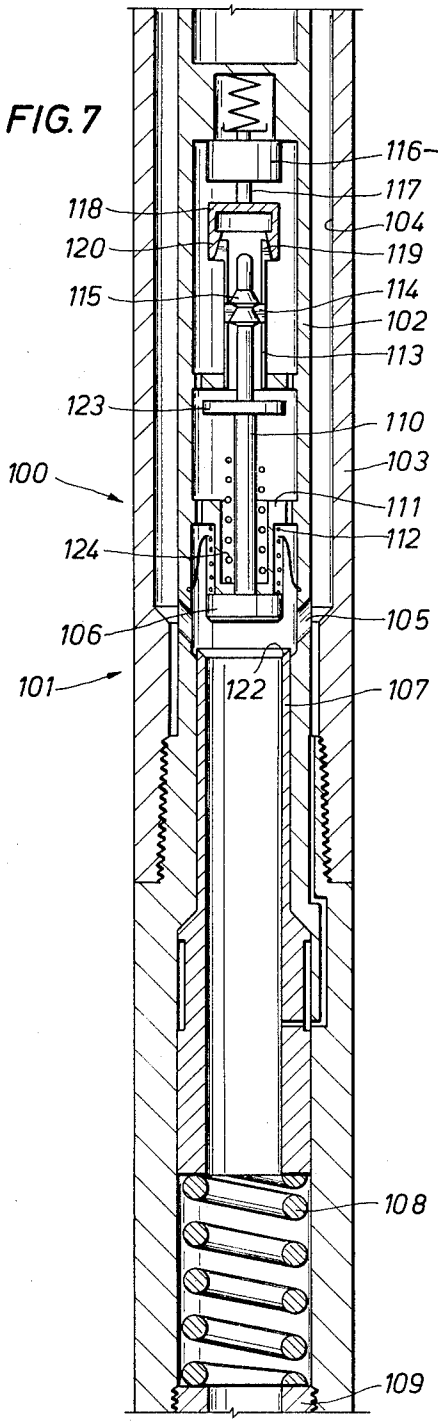
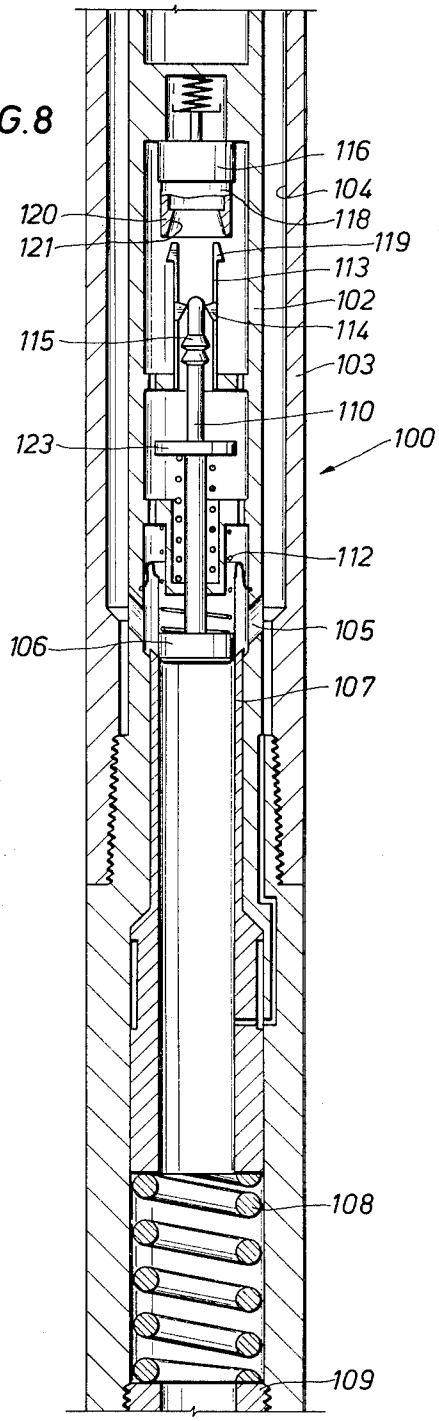


FIG. 8



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FIG. 9

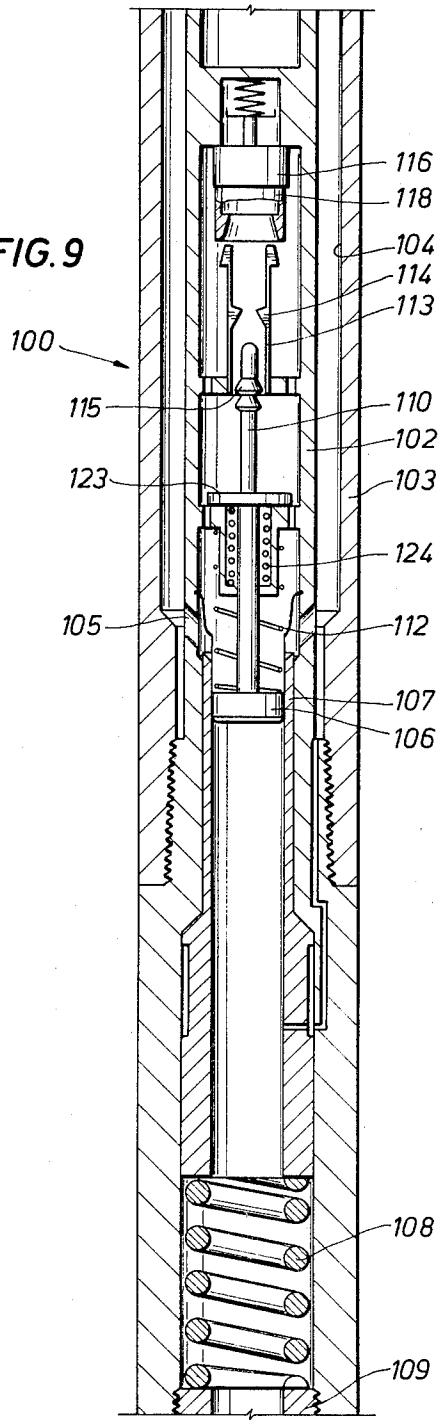
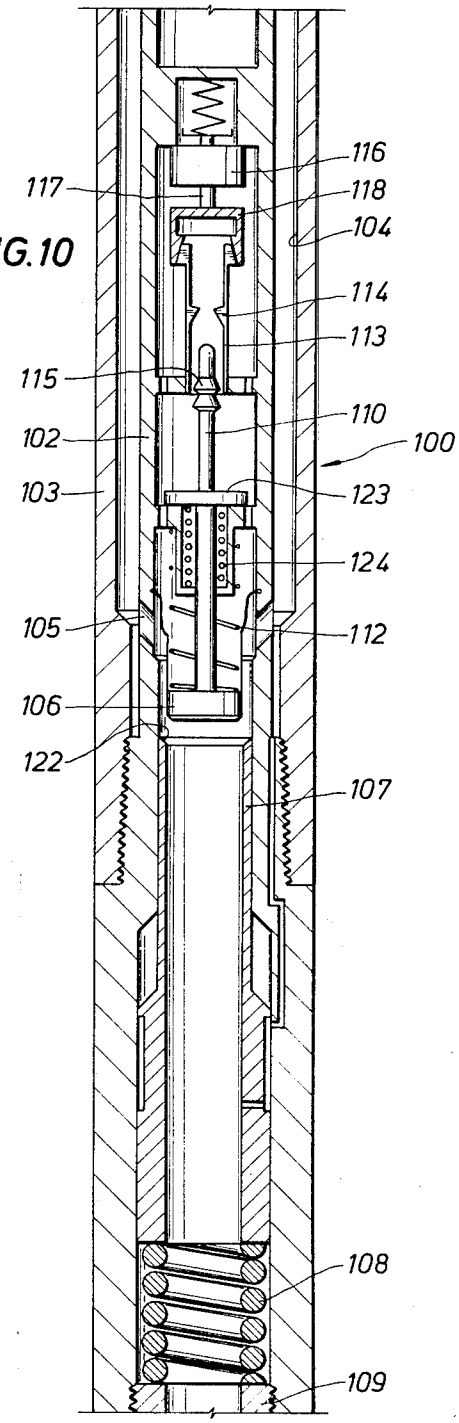


FIG. 10



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DATA-SIGNALING APPARATUS FOR WELL DRILLING TOOLS

Those skilled in the art have, of course, long recognized the benefits of obtaining various measurements at the bottom of a borehole during the course of a drilling operation. For instance, such information as the weight on the drill bit, the drill string torque, the inclination and the azimuthal direction of the borehole, bottom hole pressures and temperatures as well as various characteristics of the formations being penetrated are all measurements of significant interest.

Various proposals have, of course, been made heretofore for transmitting such measurements from the bottom of a borehole to the surface. Of the many different tools proposed, perhaps the most promising of all utilize a condition-responsive valve for selectively interrupting the flow of the circulating drilling fluid in a predetermined coded sequence representative of the measurements to produce a series of momentary pressure surges which are successively transmitted through the drilling fluid to the surface for detection by appropriate sensing devices. These proposed tools have, therefore, generally employed a typical solenoid-operated valve which is coupled to one or more condition-sensing devices by means of appropriate electronic circuitry operatively arranged for opening and closing the valve in accordance with this coded sequence.

For various reasons, however, these prior proposals have generally been considered to be unacceptable for commercial drilling operations. For instance, since the signaling valves in such prior tools have customarily been directly operated by solenoids, the mechanical forces required just for operating these solenoids become excessive in even relatively shallow wells. Moreover, by virtue of their substantial power requirements, the physical size of such solenoids make them impractical for the usual sizes of drilling tools.

Accordingly, it is an object of the present invention to provide new and improved data-signaling apparatus for use with well-drilling tools and which is specially adapted for rapidly transmitting downhole measurements to the surface with minimum electrical requirements.

This and other objects of the present invention are attained by providing a well tool adapted to be connected in a drill string having a drill bit dependently coupled thereto for excavating a borehole as a drilling fluid is circulated through the drill string and a fluid passage arranged in the tool. Data-signaling means are arranged on the tool and include condition-measuring means which are coupled to measurement-encoding means adapted for producing coded electrical signals indicative of one or more selected downhole conditions which may be experienced during the course of a drilling operation. To generate distinctive pressure pulses in the circulating drilling fluid representative of such measurements, the measurement-encoding means operatively drive pressure-signaling means arranged on the tool and including valve means adapted to momentarily block or close the fluid passage for developing each pressure pulse. Biasing means are operatively arranged for returning the valve means to a passage-opening position to await the next electrical signal. The pressure-signaling means further include an actuator which, in response to the electrical signals produced by the measurement-encoding means, only initiates the operation of the valve means. Means are operatively associated with the valve means and adapted for utilizing the circulating drilling fluid as a motive force to positively operate the valve means as well as to energize the biasing means each time the actuator is operated.

The novel features of the present invention are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may be best understood by way of the following description of exemplary apparatus employing the principles of the invention as illustrated in the accompanying drawings, in which:

FIG. **1** shows a well tool arranged in accordance with the present invention as it will appear while coupled in a drill string during the course of a typical drilling operation;

FIG. **2** is a schematic representation of a preferred embodiment of the tool shown in FIG. **1**;

FIGS. **3–5** schematically depict certain successive operating positions of a preferred embodiment of data-signaling apparatus incorporating the principles of the present invention;

FIG. **6** illustrates an alternative arrangement of one portion of the new and improved data-signaling apparatus shown in FIGS. **3–5**; and

FIGS. **7–10** respectively shown the successive operating positions of other data-signaling apparatus of a similar nature and which also incorporates the broader principles of the present invention.

Turning now to FIG. **1**, a new and improved well tool **10** arranged in accordance with the present invention is depicted coupled in a typical drill string **11** having a rotary drill bit **12** dependently coupled thereto and adapted for excavating a borehole **13** through various earth formations as at **14**. As the drill string **11** is rotated by a typical drilling rig (not shown) at the surface, substantial volumes of a drilling fluid or so-called "mud" are continuously pumped downwardly through the tubular drill string and discharged from the drill bit **12** to cool the bit as well as to carry earth borings removed by the bit to the surface as the mud is returned upwardly along the borehole **13** exterior of the drill string. As is typical, the mud stream is circulated by employing one or more high-pressure mud pumps (not shown) which continuously draw the fluid from a storage pit or vessel for subsequent recirculation by the mud pumps. It will be appreciated, therefore, that the constantly circulating mud stream flowing through the drill string **11** serves as a transmission media that is well suited for transmitting pressure surges or pulses to the surface.

In accordance with the principles of the present invention, data-signaling means **15** are arranged on the well tool **10** and include condition-measuring means **16** such as one or more condition-responsive devices, as at **17** and **18**, which are coupled to an appropriate measurement encoder **19** operatively arranged to produce a series of coded electrical signals that are representative of the measurements being obtained by the condition-responsive devices. Pressure-signaling means **20** coupled to the encoder **19** are operatively arranged to respond to these coded signals for selectively generating a corresponding series of pressure pulses in the circulating fluid by momentarily and rapidly interrupting

the flow of the drilling fluid through the drill string **11**. It will be appreciated, of course, that these transitory pressure pulses or surges will be similar to those caused by a so-called "water hammer." Thus, these pressure waves will be transmitted to the surface by way of the mud stream flowing within the drill string **11** and at the speed of sound in the particular drilling fluid. Accordingly, as will subsequently be explained in greater detail, the pressure-signaling means **20** produce these pressure pulses to provide encoded representations or data indicative of the one or more downhole conditions sensed by the condition-measuring devices **17** and **18**. This data is, in turn, successively transmitted to the surface in the form of these pressure pulses for detection and conversion into meaningful indications or records by suitable surface-located pressure-transducing apparatus **21** such as those disclosed in either U.S. Pat. No. 3,488,629 or U.S. Pat. No. 3,555,504.

Turning now to FIG. **2**, a schematic view is shown of the new and improved well tool **10** just prior to the production of a pressure surge or pulse which is to be transmitted to the surface by way of the drilling fluid being circulated through the drill string **11**. As illustrated, the well tool **10** is comprised of an elongated tubular member **22** that is coaxially arranged within a thick-wall tubular housing **23** which is tandemly coupled in the drill string **11** just above the drill bit **12**.

Although the inner member **22** could just as well be permanently mounted in the housing **23**, it is preferred to adapt the inner member for selective retrieval to the surface by way of the drill string **11**. To facilitate this, the inner bore **24** of the tubular housing **23** is reduced to provide an annular shoulder **25** on which the lower end of the tubular member **22** is cooperatively seated and releasably latched to the housing by means such as one or more inwardly contractible latch fingers **26** having outwardly enlarged heads as at **27** which are dependently arranged on the inner member and adapted to contract as they pass through the annular shoulder and then spring outwardly again to secure the inner member in its depicted position. Upright collet fingers **28** having inwardly directed shoulders **29** are mounted on the upper end of the inner tubular member **22** and cooperatively arranged for receiving a conventional wireline grapple or overshot (not shown) adapted for being coupled therewith to permit the inner member to be retrieved to the surface through the drill string **11**.

Although a self-contained power supply could be employed, it is preferred to utilize the flowing mud stream as a motivating source for generating electrical power for operation of the new and improved well tool **10**. Accordingly, in the preferred manner of accomplishing this, a reaction turbine **30** is journalled, as by a bearing **31**, to the upper end of the inner member **22** and operatively arranged to be rotatively driven by the downwardly flowing drilling fluid for driving a generator **32** coupled to the turbine by an elongated shaft **33**. To facilitate the operation of the turbine **30**, the inner bore **24** of the outer housing **23** is enlarged to provide an annular cavity or chamber **34** into which the mud stream will be discharged from the outlet ports **35** of the turbine. One or more longitudinal passages, as at **36**, are formed in the outer housing **22** for conducting the mud stream from the upper chamber **34** to another chamber **37** formed therebelow in an intermediate portion of the outer housing. It will be appreciated, therefore, that during the operation of the well tool **10**, the circulation of the drilling fluid or mud will be effective for continuously driving the turbine **30** and the generator **32** coupled thereto to produce electrical power for operating the data-signaling means **15**.

As depicted in FIG. **3**, at least a substantial portion of the mud stream leaving the intermediate chamber **37** enters one or more downwardly inclined lateral ports **38** formed at an intermediate location in the inner member **22** and is directed thereby through an annular valve seat **39** coaxially arranged within the longitudinal bore **40** of the inner member and just below the ports on through the lower portion of the inner tubular member. To produce the aforementioned pressure pulses, the pressure-signaling means **20** include an annular valve member **41** which is slidably arranged in the longitudinal bore **40** of the inner member **22** and adapted for reciprocating movement therein between an elevated position just above the fluid ports **38** and a lower port-closing position over the ports where the valve member is cooperatively received within the valve seat **39**. To prevent unbalanced longitudinally acting pressure forces from retarding the upward and downward movements of the valve member **41**, one or more longitudinal passages **42** are arranged through the valve member. Accordingly, it will be recognized that so long as the valve member **41** remains in its elevated position depicted in FIG. **3**, the drilling fluid can freely circulate from the chamber **37** through the lateral ports **38** and the valve seat **39** and pass without significant restriction on through the lower portion of the longitudinal bore **40** to the drill bit **12** therebelow. On the other hand, it will be appreciated that downward movement of the valve member **41** into the valve seat **39** will momentarily at least block or close the fluid ports **38** and produce a corresponding pressure surge or pulse which will be transmitted back up the mud stream in the drill string **11** for detection at the surface.

To actuate the valve member **41**, the pressure-signaling means **20** further include an elongated rod **43** which is coaxially arranged within an upright tubular extension **44** secured to the valve member and adapted for sliding axial movement in relation thereto. The lower end of the elongated rod **43** is enlarged, as at **45**, to provide a head adapted to closely fit within the longitudinal bore **40** below the valve seat **39** as well as to define an upwardly directed surface **46** which, in the elevated position of the slidable rod depicted in FIG. **3**, is located just above the flow path of the drilling fluid passing through the lateral ports **38**. To further assure that the upper surface **46** of the enlarged head **45** is out of the flow path of the drilling fluid, the lower end of the valve member **41** is counterbored, as at **47**, for complementally receiving the uppermost portion of the head.

It will be appreciated from FIG. **4**, however, that a limited downward movement of the slidable rod **43** in relation to the valve member **41** will position the upwardly directed surface **46** at least partially in the main flow path of the drilling fluid passing through the ports **38**. Thus, the impingement of the drilling fluid on the surface **46** will be effective for shifting the elongated rod **43** further downwardly in relation to the ports **38** and the valve member **41** to position the head **45** within

the longitudinal bore **40** below the valve seat **39**. This downward movement of the elongated rod **43** will also bring an enlarged shoulder **48** arranged thereon downwardly into engagement with an enlarged head **49** formed on the upper end of the tubular extension **44** of the valve member **41**.

Accordingly, once the rod **43** has moved downwardly a sufficient distance to engage the shoulder **48** with the enlarged head **49**, continued downward travel of the elongated rod will be effective for shifting the valve member **41** downwardly to its port-blocking position within the valve seat **39** to halt further flow of the drilling fluid through the ports **38**. It will be appreciated, therefore, that the initial downward travel of the elongated rod **43** is readily accomplished by the impingement of the drilling fluid on the surface **46** as the fluid passes through the ports **38**. Moreover, once the lower enlarged head **45** has been moved into the longitudinal bore **40** as depicted in FIG. **4**, the flow of the drilling fluid will be sufficiently interrupted to produce a pressure surge which is effective for carrying the rod **43** further downwardly to positively shift the valve member **41** to its port-closing position (FIG. **5**) by virtue of the pressure forces acting downwardly on the surface **46**.

To return the elongated rod **43** and the valve member **41** to their elevated positions after the valve member has been closed, biasing means are provided such as a relatively stout compression spring **50** which is coaxially arranged around the upper portion of the rod and supported on an inwardly directed shoulder **51** formed on the inner member **22**. A cupped ring **52** is coaxially arranged around the elongated rod **43** and slidably positioned between the upper end of the spring **50** and the lower surface of an inwardly directed shoulder **53** arranged within the inner member **22** above the shoulder **51**. In this manner, by arranging an outwardly directed shoulder **54** on the elongated rod **43** to be normally spaced slightly above the slidable ring **52**, the initial downward travel of the elongated rod **43** will be effective for bringing the shoulder **54** into engagement with the ring so as to then compress the spring **50** upon further downward travel of the rod. A light spring **55** is mounted between the cup-shaped ring **52** and the shoulder **54** thereabove to normally position the enlarged head **45** in the counterbore **47**.

Biasing means such as a relatively weak compression spring **56** are arranged around the tubular extension **44** between an inwardly-directed shoulder **57** on the inner member **22** below the shoulder **51** and the enlarged head **49** on the tubular extension. Thus, it will be appreciated that by arranging the spring **56** as illustrated, downward movement of the valve member **41** and the tubular extension **44** by the elongated rod **43** will be effective for compressing the spring. Accordingly, once the stout spring **50** has returned the elongated rod **43** and the valve member **41** to their respective elevated positions, the lighter spring **56** will be effective for retaining the valve member in its elevated position.

It will be appreciated that by virtue of the longitudinal spacing that is normally present between the shoulder **54** and the ring **52**, the rod **43** is free to travel downwardly a short distance and without significant restraint before encountering the upwardly-acting forces of the springs **50** and **56**. This will, therefore, assure that the fluid-impingement surface **46** is moved well into the main flow stream of the drilling fluid passing through the ports **38** before the ring **52** is engaged so that the fluid-impingement forces acting on the rod **43** will then be effective for carrying it further downwardly against the increasing upwardly acting spring forces imposed on the rod by the compression springs **50** and **56**.

To initiate the operation of the valve member **41**, the pressure-signaling means **20** also include a solenoid **58** which is mounted within the inner member **22** and operatively arranged for shifting the rod **43** downwardly at least as far as is necessary for the fluid-impingement surface **46** to be moved into the flow path of the drilling fluid passing through the ports **38**. In the preferred manner of operatively coupling the solenoid **58** to the elongated rod **43**, the axially movable armature or plunger **59** of the solenoid is adapted to move downwardly upon energization of the solenoid; and, as depicted in FIG. **4**, move the upper end of the elongated rod downwardly a sufficient distance to position the fluid-impinging surface **46** in the flow stream of the drilling fluid passing through the ports **38**. A diaphragm **60** is arranged across the solenoid plunger **59** to permit the solenoid **58** to be enclosed in oil or the like.

It will be recognized, of course, that by virtue of the streamlined configuration of the enlarged head **45**, downward movement of the elongated rod **43** will require only a minimum force so as to make it unnecessary for the solenoid **58** to be either of significant physical size or require excessive power for its operation. As previously noted, once the fluid-impinging surface **46** has entered the main flow stream of the drilling fluid passing through the ports **38**, the aforementioned continued downward travel of the elongated rod **43** will be accomplished by the impingement and pressure surge forces developed by this fluid until the valve member **41** has closed the fluid ports.

As shown in FIG. **6**, it will be appreciated that an upright solenoid armature **59'** can alternatively be tandemly mounted on the upper end of the elongated rod **43** and operatively arranged in relation to an annular solenoid coil **58'** for shifting the rod downwardly as required to bring the fluid-impinging surface **46** (not shown in FIG. **6**) into the stream of the drilling fluid flowing through the ports **38**. Then, once the impingement of the drilling fluid urges the elongated rod further downwardly, the armature **59'** mounted on the upper end of the rod **43** may well be moved entirely below the solenoid coil **58'**.

In any event, it should be noted that the solenoid **58** (or **58'**) needs only to be capable of shifting the elongated rod **43** downwardly a relatively short distance and that this downward movement requires only the minimal force necessary to compress the light spring **55**. MOreover, with either of these alternative arrangements of the solenoids **58** and **58'**, should the valve member **41** accidentally become jammed in the valve seat **39** by debris or the like lodged in the ports **38**, subsequent application of power to the solenoid will not damage it. It is, therefore, of significance to the present invention to realize that the motivating forces supplied by either of the solenoids **58** and **58'** are only minimal since the substantial impingement and pressure forces imposed on the surface **46** are fully capable of closing

the valve member **41** once the impingement surface is shifted into the flow stream of the drilling fluid passing through the ports **38**.

Referring again to FIGS. **1** and **2**, once the well tool **10** is in position within the borehole **13**, the measuring devices **17** and **18** will function to provide measurements of the particular conditions which are being monitored and cause the measurement encoder **19** to produce the series of electrical signals representative of these conditions. Each of these signals will, therefore, momentarily energize the solenoid **58** to initiate operation of the pressure-signaling means **20** as in FIGS. **3** and **4**. Thus, each time the solenoid **58** is energized, the elongated rod **43** will be shifted downwardly so as to bring the fluid-impingement surface **46** into the stream of the drilling fluid passing through the ports **38**. Then, as depicted in FIG. **5**, the downwardly acting forces imposed on the impingement surface **46** by the drilling fluid will carry the elongated rod **43** further downwardly for shifting the valve member **41** into momentary seating engagement within the valve seat **39** as well as for simultaneously compressing the springs **50** and **56**. Once the springs **50** and **56** are energized, the elongated rod **43** and the valve member **41** will be returned to their initial elevated positions as depicted in FIG. **3**.

To understand the underlying principle of the operation of the pressure-signaling means **20**, reference should be made to FIG. **4**. At this point in the sequence, the enlarged head **45** has just moved into the longitudinal bore **40** just below the valve seat **39**. This movement will, of course, significantly interrupt the downward flow of the circulating drilling fluid to produce a substantial positive dynamic pressure which is imposed on the impingement surface **46**. At the same time, the continued flow of the drilling fluid that is then below the enlarged head **45** will simultaneously produce a reduced pressure in the longitudinal bore **40** below the head. As a result, a substantial downwardly acting pressure force will be imposed on the surface **46** to drive the elongated rod **43** further downwardly to shift the valve member **41** to its port-closing position (FIG. **6**). It will, of course, be appreciated that this downwardly-acting pressure force will be equal to the pressure differential imposed on the effective cross-sectional area of the surface **46**.

As the rod **43** and the valve member **41** are driven downwardly, the springs **50** and **56** will, of course, be compressed to develop corresponding upwardly acting spring forces tending to return the members to their respective elevated positions. Once the valve member **41** closes the ports **38**, the impingement surface **46** will be isolated from the aforementioned positive pressure forces. Thus, once the positive pressure in the longitudinal bore **42** above the enlarged head **45** has been reduced so as to be equalized with the pressure below the head (by way of the passages **42** and the narrow clearance space around the head and the adjacent wall of the inner member **22**), the spring force provided by the now-compressed spring **50** will be effective for driving the elongated rod **43** upwardly. This upward travel of the rod **43** will, therefore, reposition the enlarged head **45** in the counterbore **47** and then shift the valve member **41** upwardly as the elongated rod is returned to its initial elevated position by the spring **50**.

It will be appreciated, therefore, that each time the solenoid **58** (or **59'**) is energized, the valve member **41** will be rapidly closed and then quickly reopened so as to produce a momentary pressure surge without unduly retarding the continued circulation of the drilling fluid. As previously mentioned, the pressure pulses which are sequentially produced by the repetitive closing and opening of the valve member **41** will be transmitted to the surface by way of the stream of drilling fluid being circulated downwardly through the drill string **11**. Thus, as these pressure pulses sequentially arrive at the surface, the surface apparatus **21** will detect them to produce a meaningful record which is indicative of the conditions being monitored by the condition-responsive devices **17** and **18**.

Turning now to FIG. **7**, the intermediate portion of a well tool **100** is shown to illustrate an alternative embodiment of pressure-signaling means **101** which broadly incorporate the principles of the present invention. As depicted, the well tool **100** includes a tubular inner member **102** which is coaxially arranged within an outer tubular housing **103**. Although the inner member **102** could be releasably secured to the outer housing **103** in a manner similar to that previously described with reference to the well tool **10**, it is preferred to permanently mount the inner member within the housing as illustrated.

Although it is not illustrated, the upper portion of the well tool **100** is arranged in a similar fashion to the well tool **10** and carries a turbine-driven electrical generator (not shown) which is driven by the continuous circulation of the drilling fluid passing from the drill string **11** into the upper end of the well tool **100**. The well tool **100** is cooperatively arranged with either one or more longitudinal passages or the annular space **104** between the inner and outer members **102** and **103** through which the drilling fluid will pass after leaving the turbine-generator (not shown) thereabove. In either case, the downwardly flowing drilling fluid is directed into one or more downwardly inclined ports **105** arranged near the lower end of the inner member.

The pressure-signaling means **101** include a valve member **106** coaxially mounted within the inner member **102** and adapted for axial movement therein between an elevated position as depicted in FIG. **7** and a port-closing position where the valve member is cooperatively received within the upper end of a tubular valve seat **107**. As will subsequently be explained, the valve seat **107** is slidably mounted in the inner member **102** and normally retained in its depicted elevated position by biasing means such as a compression spring **108** supported on an inwardly directed shoulder **109** on the outer housing **103** and engaged with the lower end of the valve seat. To support the valve member **106** for reciprocating movement within the inner member **102**, an upright extension or rod **110** is secured to the valve member and extended upwardly through an annular guide **111** arranged thereabove within the inner member **102**. Biasing means, such as a compression spring **112** compressed between the guide **111** and the valve member **106**, are operatively arranged for urging the valve member downwardly toward its port-closing position.

To releasably retain the valve member **106** in its elevated position, latching means are provided such as

one or more upright leaf springs or yieldable fingers **113** which are secured within the inner member **102** and releasably coupled to the rod **110** by inwardly directed lugs as at **114** on the mid-portion of each finger which are adapted to remain engaged under one or more outwardly enlarged shoulders **115** spaced along the upper portion of the elongated rod so long as the fingers are retained in their respective inwardly contracted positions illustrated in FIG. **7**. To retain the fingers **113** in their latching positions, a solenoid **116** is coaxially mounted within the inner member **102** and includes a vertically reciprocating armature **117** carrying a downwardly opening cup-like member **118** which is adapted for movement between an elevated position above the latch fingers and the lower position depicted in FIG. **7** wherein the cup at least partially encloses the upper ends of the fingers.

In the preferred embodiment illustrated, upwardly directed wedge-shaped heads, as at **119**, are mounted on the upper ends of each of the several fingers **113** and an annular ring **120** is arranged around the cup **118** to define an internal downwardly directed wedge-like surface **121** which is complemental to the opposed surfaces of the wedge-shaped heads. Thus, so long as the cup **118** is disposed over the upright fingers **113**, the ring **120** will cooperatively engage the wedge-shaped heads **119** to restrain the fingers against moving outwardly from their respective positions shown in FIG. **7**. In this manner, so long as the fingers **113** are retained from moving outwardly, the inwardly directed lugs **114** will be maintained in coengagement under one of the enlarged shoulders **115** on the elongated rod **110**. It will, therefore, be recognized that the spring **112** is urging the valve member **106** and the rod **110** downwardly and that it is only the coaction of the lugs **114** under the shoulder **115** which maintains the valve member in its elevated position.

On the other hand, as will subsequently be described in further detail, it will be appreciated that once the solenoid **116** is energized to withdraw the cup **118** from over the enlarged heads **119**, the cooperative camming action between the enlarged shoulder **115** and the inwardly directed lugs **114** will be effective for momentarily springing the fingers **113** outwardly to free the elongated rod **110** and the valve member **106** for downward movement. Thus, once the solenoid **116** is energized, the compression spring **112** will be effective for forcefully driving the valve member **106** downwardly once the enlarged shoulder **115** has expanded the mid-portions of the fingers **113** sufficiently to disengage the enlarged shoulder from the inwardly directed lugs **114**.

Accordingly, as depicted in FIG. **8**, once the valve member **106** enters the valve seat **107**, the circulating drilling fluid will be momentarily halted so as to produce a transitory pressure surge or pressure pulse in the nature of a water hammer. THose skilled in the art will, of course, appreciate that the dynamic pressures produced by such water hammers are quite substantial. Thus, by virtue of the rapid movement of the valve member **106** into seating engagement within the valve seat **107**, the substantial dynamic pressure force which is developed will be imposed on the upper end **122** of the valve seat and will be effective for urging the valve seat downwardly in relation to the outer housing **103**. In view of the substantial magnitude of this pressure force acting on the effective cross-sectional area of the upper end **122** of the valve seat **107**, the valve seat will be shifted downwardly to begin compressing the spring **109**. This same dynamic force will also be imposed on the upper face of the valve member **106** to also move it downwardly into the valve seat **107**.

It will be noted from FIG. **9** that as the valve seat **107** begins moving downwardly, the valve member **106** will be abruptly halted as an enlarged shoulder **123** on the elongated rod **110** engages the guide **111**. Thus, the dynamic pressure force imposed on the upper end **122** of the valve seat **107** will be effective for shifting the valve seat away from and out of engagement with the momentarily halted valve member **106**. Moreover, once the valve seat **107** is withdrawn from over the valve member **107** as depicted in FIG. **10** to equalize the pressure differential, a spring **124** arranged between the guide **111** and the shoulder **123** will now have been compressed so as to quickly return the valve member and the elongated rod **110** upwardly toward their initial elevated positions.

During this same time interval, it will be noted by comparison of FIGS. **9** and **10** that the solenoid **116** has now been de-energized so as to reposition the cup **118** back over the enlarged heads **119** of the latch fingers **113**. Thus, once the upper ends **119** of the fingers **113** are again reconfined, it will be appreciated that as the enlarged shoulders **115** on the elongated rod **110** move upwardly past the inwardly directed lugs **114**, the mid-portions of the fingers will be momentarily cammed outwardly. Then, once one or more of the shoulders **115** are above the lugs **114**, the mid-portions of the fingers **113** will again contract to resecure the elongated rod **110** and the valve member **106** in their elevated positions as depicted in FIG. **7**. Similarly, the downwardly-acting dynamic pressure forces acting on the valve seat **107** will be quickly terminated as the valve member **106** is withdrawn therefrom so that the compression spring **124** will rapidly return the valve seat upwardly to its elevated position as illustrated in FIG. **7**.

Accordingly, it will be appreciated that the new and improved data-signaling apparatus of the present invention is particularly adapted for producing pressure pulses which are selectively coded for transmitting information through the drilling fluid from a borehole to the surface. To produce these pressure pulses, an electrically operated actuator is operatively arranged for initiating the operation of valve means which, once initiated, employ the circulating drilling fluid as a motive force for operating the valve means.

While particular embodiments of the present invention have 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.

What is claimed is:

1. Apparatus adapted for transmitting data to the surface during the drilling of a borehole and comprising: a tubular drill string having a borehole-drilling device dependently coupled thereto and defining a flow passage for circulating drilling fluids between the sur-

face and said borehole-drilling device; data-signaling means on said drill string adapted for producing electrical signals indicative of at least one downhole condition; and pressure-signalling means on said drill string adapted for producing pressure pulses in drilling fluids flowing through said drill string which are representative of the electrical signals produced by said data-signaling means, said pressure-signaling means including valve means adapted for movement between a passage-opening position and a passage-obstructing position for obstructing the flow of drilling fluids through said flow passage, a valve actuator adapted for movement between an inactive position and first and second spaced positions in said flow passage, said valve actuator having a fluid-impingement surface thereon adapted to be moved into the path of drilling fluids passing through said flow passage upon movement of said valve actuator to its said first position and operatively arranged for utilizing such fluids for carrying said valve actuator to its said second position, means on said valve actuator operatively arranged to engage said valve means only after said valve actuator is moved to its said first position and then shift said valve means to said passage-obstructing position as said valve actuator is carried to its said second position, first means responsive to said electrical signals adapted for moving said valve actuator to its said first position, and second means adapted for returning said valve actuator to its said inactive position and returning said valve means to said passage-opening position.

2. The apparatus of claim 1 further including means adapted to be located at the surface and responsive to said pressure pulses transmitted to the surface for providing indications of said pressure pulses.

3. The apparatus of claim 1 wherein said first means include an electrical solenoid coupled to said data-signaling means operatively associated with said valve actuator and adapted for initiating movement thereof to its said first position upon energization of said solenoid by said data-signaling means.

4. The apparatus of claim 1 wherein said second means include means adapted for reducing pressure differentials across said valve means after said valve means are in said passage-obstructing position, and biasing means operable only upon movement of said valve actuator to its said second position for returning said valve actuator to its said inactive position and returning said valve means to said passage-opening position once such pressure differentials across said valve means are reduced.

5. Apparatus adapted for transmitting data to the surface during the drilling of a borehole and comprising: a body adapted for connection in a tubular drill string and having a flow passage arranged to carry drilling fluids between the surface and a borehole-drilling device dependently coupled therebelow; and pressure-signaling means on said body and including means defining a valve seat in said flow passage, an annular valve member operatively arranged in said flow passage and adapted for longitudinal movement into and out of engagement with said valve seat, a valve actuator coaxially arranged within said valve member and operatively adapted for longitudinal movement in relation to said body and said valve member between first and second spaced positions on opposite sides of said valve seat, an enlarged portion on said valve actuator adapted to pass through said valve seat as said valve actuator is moved between its said first and second positions, means on said enlarged portion defining a fluid-impingement surface adapted to be struck by drilling fluids entering said valve seat once said valve actuator is moved away from it said first position and operatively arranged for such fluids to carry said valve actuator on to its said second position, electrical means operable in response to electrical signals for initiating movement of said valve actuator away from its said first position, first means on said valve actuator adapted to engage said valve member after said valve actuator has moved away from its said first position and operatively arranged for carrying said valve member into engagement with said valve seat as said valve actuator is moved to its said second position, and second means operatively arranged for returning said valve actuator to its said first position and carrying said valve member out of engagement with said valve seat.

6. The apparatus of claim 5 wherein said second means include baising means operative only upon movement of said valve actuator to its said second position for returning said valve actuator to its said first position, and means on said valve actuator adapted to engage said valve member as said valve actuator is returned toward its said first position for carrying said valve member out of engagement with said valve seat by the time that said valve actuator reaches its said first position.

7. The apparatus of claim 5 wherein said second means include means adapted for reducing pressure differentials across said valve member once said valve member is engaged with said valve seat, and biasing means operative only upon movement of said valve actuator to its said second position for returning said valve actuator to its said first position once such pressure differentials across said valve member are reduced, and means on said valve actuator adapted to engage said valve member as said valve member is returned toward its said first position for carrying said valve member out of engagement with said valve seat by the time that said valve actuator reaches its said first position.

8. The apparatus of claim 7 further including second biasing means adapted for retaining said fluid-impingement surface against said valve member while said valve actuator is in its said first position and said valve member is disengaged from said valve seat.

9. Apparatus adapted for determining at least one downhole condition while excavating a borehole and comprising: a tubular drill string having a borehole-excavating device dependently coupled thereto and adapted for circulating drilling fluids between the surface and said borehole-excavating device; data-signaling means on said drill string adapted for producing electrical signals indicative of at least one downhole condition; and pressure-signaling means adapted for developing pressure pulses in drilling fluids flowing through said drill string for transmission through such fluids to the surface and including first means coupled in said drill string and defining a fluid passage for conducting drilling fluids between said drill string and said borehole-excavating device, second means movably arranged on said first means for movement between a

normal position away from said flow passage and an operating position in said flow passage, third means movably arranged on said first means for movement between a normal position allowing flow of drilling fluids through said flow passage and an operating position for cooperating with one of said first and second means to temporarily retard flow of drilling fluids through said flow passage for producing said pressure pulses, actuating means including electrical means operable in response to said electrical signals for selectively moving said second means away from its said normal position, fluid-responsive means operatively arranged on one of said movable means for cooperatively moving said one movable means from one of its said positions to the other of its said positions, and biasing means responsive only after movement of said one movable means from its said one position for respectively returning said second and third movable means to their said normal positions.

10. The apparatus of claim **9** further including means adapted to be located at the surface and responsive to said pressure pulses transmitted to the surface for providing indications of said pressure pulses.

11. Apparatus adapted for determining at least one downhole condition while excavating a borehole and comprising: a tubular drill string having a borehole-excavating device dependently coupled thereto and defining a flow passage for circulating drilling fluids between the surface and said borehole-excavating device; data-signaling means on said drill string adapted for producing electrical signals indicative of at least one downhole condition; and pressure-signaling means on said drill string adapted for selectively developing pressure pulses in drilling fluids flowing through said fluid passage for transmission through said drill string to the surface and including valve means adapted for reciprocating movement between passage-opening and passage-closing positions in said fluid passage, fluid-obstructing means adapted for reciprocating movement back and forth between an inactive position and an active position obstructing said fluid passage, means cooperatively arranged between said fluid-obstructing means and said valve means and adapted for moving said valve means to said passage-closing position only upon movement of said fluid-obstructing means to said active position for producing said pressure pulses, electrical means operable in response to said electrical signals for selectively initiating movement of said fluid-obstructing means toward said active position, fluid-responsive means operatively arranged on said fluid-obstructing means and operable only upon movement thereof away from said inactive position for utilizing drilling fluids flowing through said fluid passage to move said fluid-obstructing means to said active position, first biasing means responsive only to movement of said fluid-obstructing means to said active position for then returning said fluid-obstructing means to said inactive position, and second biasing means responsive only to movement of said valve means to said passage-closing position for then returning said valve means to said passage-opening position.

12. The apparatus of claim **11** further including means adapted to be located at the surface and responsive to said pressure pulses transmitted to the surface for providing indications of said pressure pulses.

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