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C.I.Y. SEARCH ROOM

Nov. 4, 1958 E. W. PETERSON 2,859,013

BOREHOLE LOGGING SIGNALING SYSTEM

Filed March 1, 1954 4 Sheets-Sheet 1

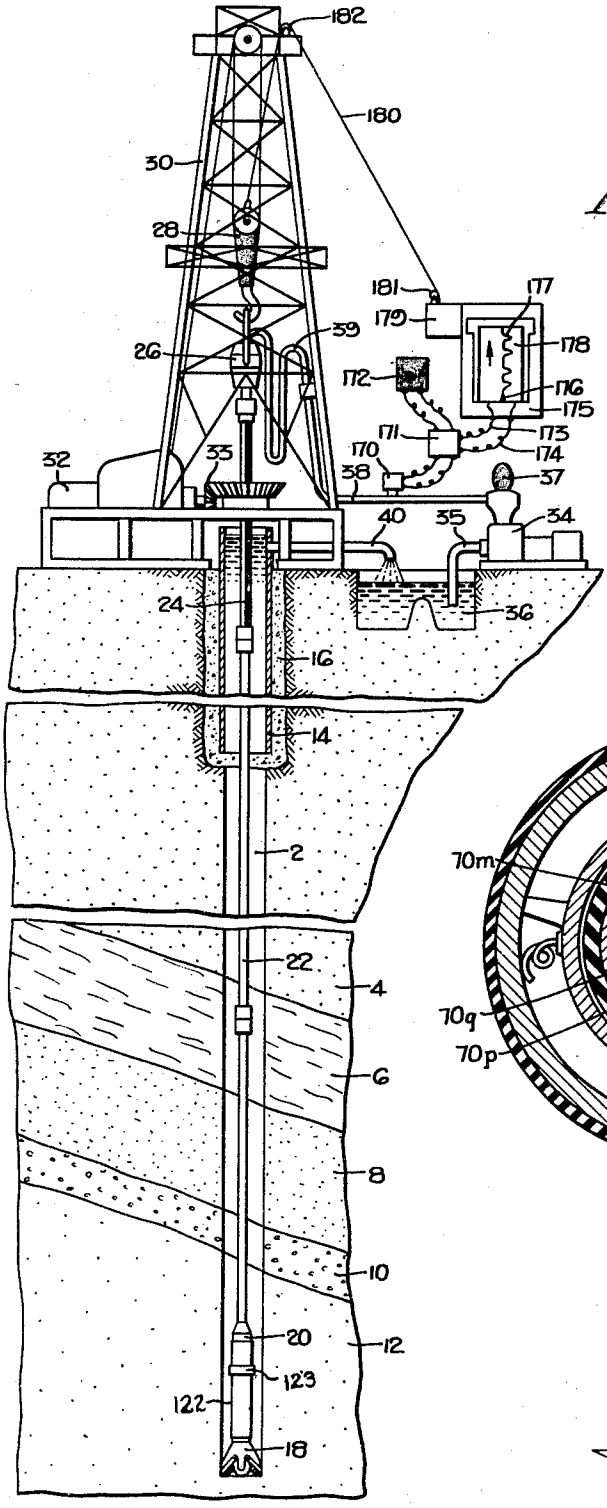


FIG. 1.

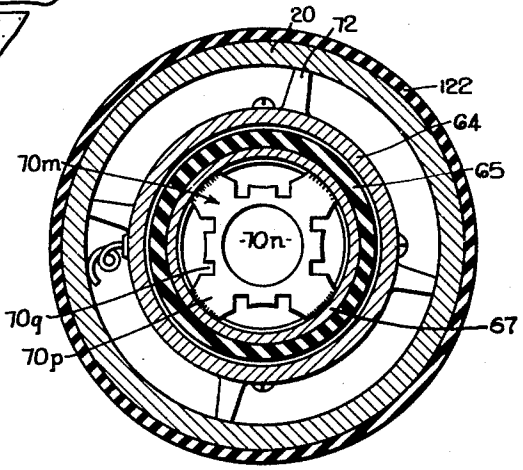


FIG. 6.

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BOREHOLE LOGGING SIGNALING SYSTEM

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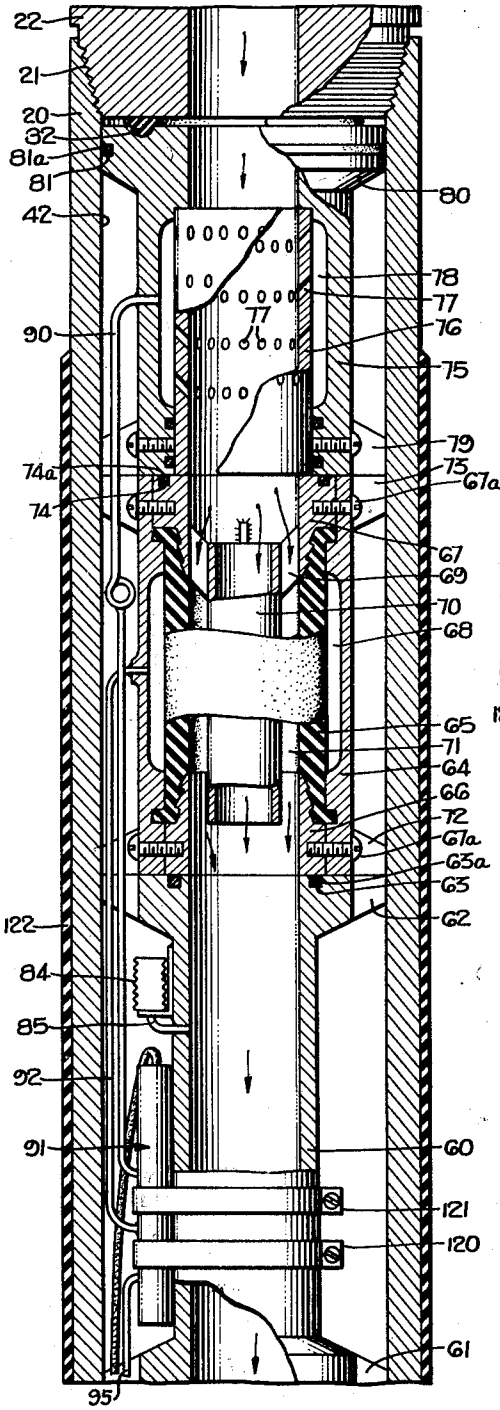


FIG. 2a.

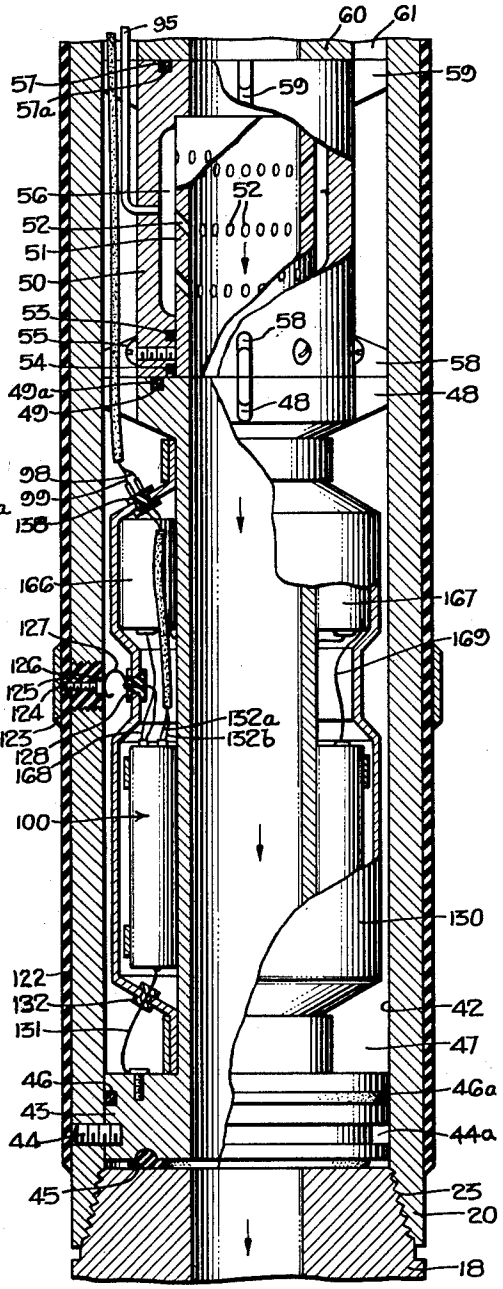


FIG. 2b.

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BOREHOLE LOGGING SIGNALING SYSTEM

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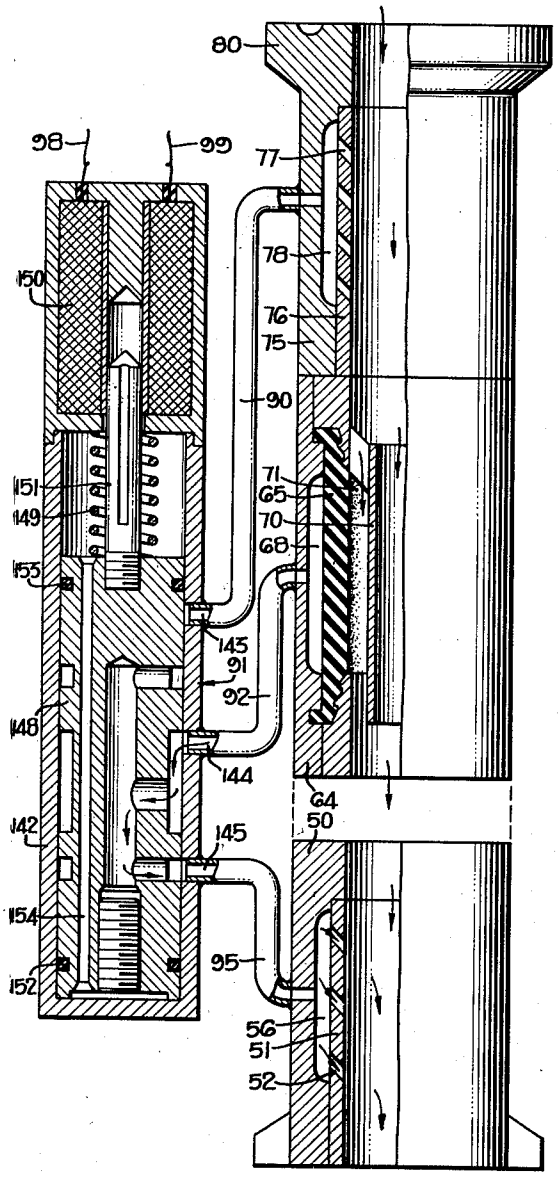


FIG. 3a.

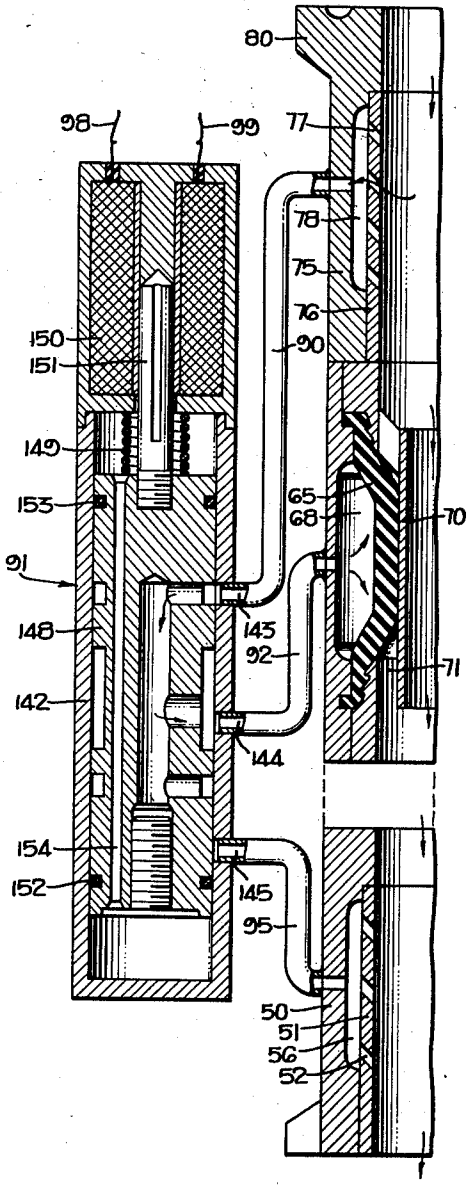


FIG. 3b.

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BOREHOLE LOGGING SIGNALING SYSTEM

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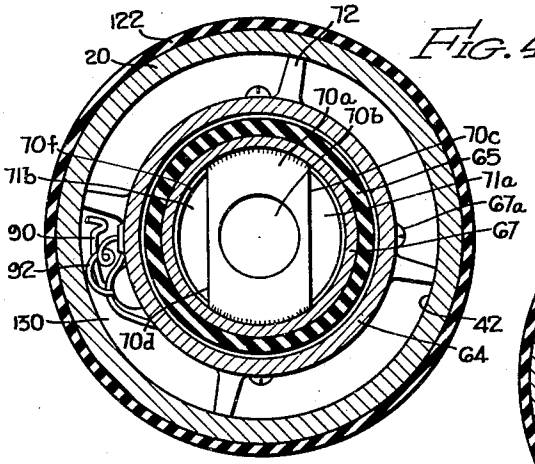


FIG. 4.

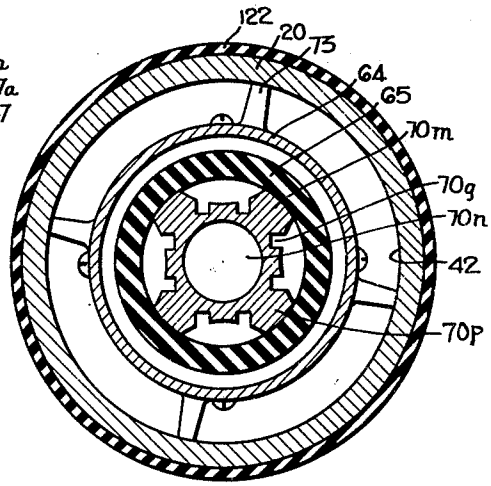


FIG. 7a.

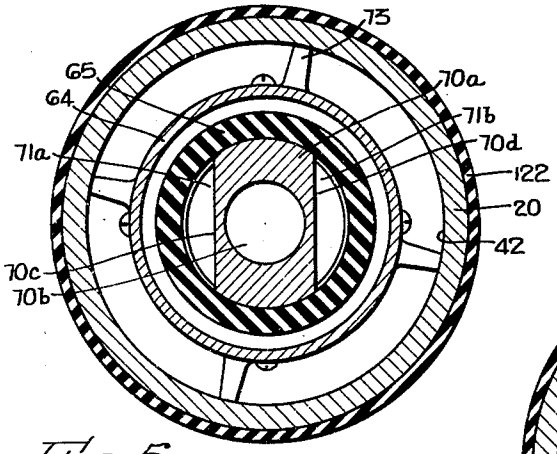


FIG. 5a.

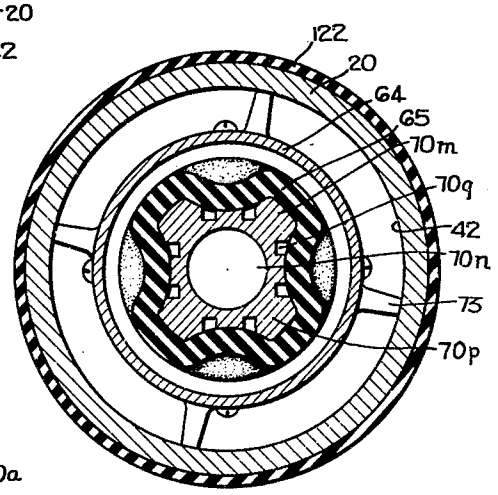


FIG. 7b.

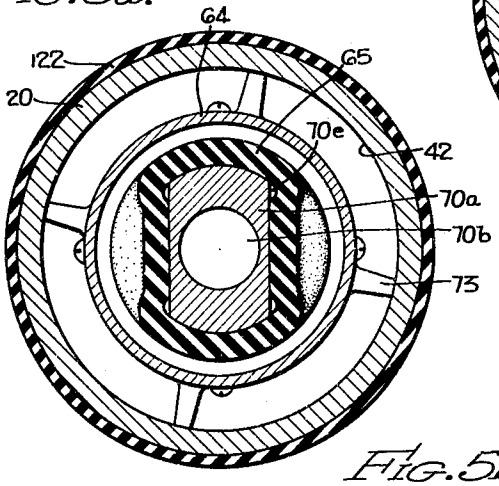


FIG. 5b.

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BOREHOLE LOGGING SIGNALING SYSTEM

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Application March 1, 1954, Serial No. 413,397

11 Claims. (Cl. 255—1)

The invention hereinafter disclosed relates in general to earth borehole logging systems of the type wherein signals representative of desired information such as various physical quantity measurements obtained by one or more measurement devices within a well borehole may be transmitted to a point outside the borehole for recording, analysis, or other purposes during and without interruption of the drilling operation.

More particularly, the invention relates to improvements in the before-mentioned type of borehole logging systems, whereby the stream of drilling fluid normally pumped downwardly under pressure through the interior of a hollow drill string is, in addition to being employed as the transmission medium serving to transmit measurement-representing signals to the top of the borehole, also employed in a novel manner to energize the signal-producing means within the borehole.

Borehole logging systems adapted for logging while drilling and which have utilized energy derived from the moving drilling fluid as a source of power at the bottom of the borehole have, because of the relatively large power requirements of the kind of apparatus heretofore used, required for such purpose impellers, turbines, and the like devices, the rotors of which were situated in the drilling fluid stream and were coupled to drive either an electric generator or a complicated arrangement of mechanical parts which were in turn utilized to furnish power to the measurement and signal-producing devices. These systems suffered the obvious disadvantages of requiring at least one rotating shaft or member extending from within a relatively protected enclosure through a seal and into the stream of abrasive drilling fluid, and from having a relatively large number of somewhat complicated and delicate moving parts located in an environment of severe mechanical vibration and shock. Also, large drilling cuttings or chips or other solid material carried by the circulating drilling fluid were apt to clog or damage such turbine and impeller devices and thereby interrupt the proper operation of the apparatus.

With the previously noted and other evident disadvantages of prior art borehole logging systems in view, it is an important object of the present invention to provide in a borehole logging system a simple means directly utilizing a portion of the pressure gradient along the drilling fluid stream to move a flow-changing means into flow-changing relationship with the drilling fluid stream, whereby a signaling flow-change or pressure-change is produced in the drilling fluid.

Another object of the invention is to provide a system of the type before-mentioned comprising a simple flow-changing device which cannot be choked by drill cuttings.

Another object of the invention is to provide a system for borehole logging while drilling comprising a simple means utilizing kinetic energy of the drilling fluid stream to produce one or more signaling pressure-changes in the drilling fluid stream.

Another object of the invention is to provide a simple drilling fluid flow-restricting device which, when flow restricting movement thereof is initiated, becomes largely self-energizing, and requires only a relatively small amount of energy to initiate and control such action of the device.

An additional object of the invention is to provide simple means utilizing directly a portion of the energy of a drilling fluid stream to move a drilling fluid flow-changing means into flow-changing attitude or relationship with the drilling fluid stream.

A still further object of the invention is to provide a system of well borehole logging in which energy possessed by the drilling fluid stream is directly utilized by simple means to produce a pressure-change signal in the drilling fluid stream.

Broadly, the present invention resides in a novel apparatus and method by which useful information obtained by suitable instrumentalities within a borehole may be transmitted to the surface of the earth by a signal in the form of changes in character of flow of the drilling fluid, such changes preferably being in the form of a plurality of repetitive pressure-changes in the drilling fluid stream in the drill string, either during drilling or between drilling periods, or both, utilizing the normal pressure gradient in a portion of the drilling fluid stream to supply substantially all of the energy required for initiating and producing such pressure changes. More specifically, the pressure in the drilling fluid stream is, by suitable means, picked up or sensed at a first point and transmitted or translated to a flexible member positioned to vary the resistance to flow of the fluid stream at another point, there preferably being a pressure differential in the stream between the two points, due to the mentioned pressure gradient, to cause the flexible member to be flexed into the stream to increase the resistance to flow thereof or flexed out of the stream to decrease the resistance to flow thereof, thereby producing pressure-change signals in the stream. Since substantially all of the energy required to produce the drilling fluid pressure-change signals may thus be derived directly from the drilling fluid stream, and may be directly utilized without conversion to another form of energy, the turbogenerator or rotary means heretofore employed may be dispensed with; with the remaining requirement only that an actuating or triggering means of small size and requiring only an extremely small amount of energy for its operation be employed for initiating and controlling the action of the signaling apparatus.

The hereinbefore mentioned and other objects, advantages, and features of novelty will become evident hereinafter wherein a preferred embodiment of apparatus and best mode contemplated for carrying out the invention are described in conjunction with the drawings, in which like reference characters designate the same or similar parts throughout the several views, and in which:

Figure 1 is a view, partly in elevation and partly in longitudinal section, illustrating a typical drilling rig and an earth borehole produced thereby, and including a general arrangement and location of the apparatus of the invention;

Figure 2*a* is an enlarged longitudinal view, partly in section, of a part of the apparatus shown in Figure 1;

Figure 2*b* is an enlarged longitudinal view, partly in section, of a part of the apparatus shown in Figure 1 and forming an extension of the structure depicted in Figure 2*a*;

Figure 3*a* is a longitudinal sectional view, partly diagrammatic illustrating a portion of the hydraulic fluid connections and apparatus of Figures 2*a* and 2*b*, and showing the position of certain of the apparatus elements at one stage of a signaling cycle;

Figure 3*b* is a fragmentary view of apparatus shown in Figure 3*a* and illustrating the position of certain of

the apparatus elements at another stage of the signaling cycle;

Figure 4 is a transverse sectional view of a modified form of valve structure;

Figure 5a is a transverse sectional view of the modified form of the valve structure of Figure 4;

Figure 5*b* is a transverse sectional view of the apparatus of Figure 5*a* showing the valve means in drilling fluid flow-restricting position;

Figure 6 is a transverse sectional view of a second modified form of the valve structure;

Figure 7*a* is a transverse sectional view of the second modified form of the valve structure;

Figure 7*b* is a transverse sectional view of the apparatus of Figure 7*a* showing the valve means in flow-restricting attitude.

Referring now to the drawings, and more specifically to Figure 1, there is shown a typical well borehole **2** formed by a conventional rotary drilling method through successive strata **4**, **6**, **8**, **10** and **12** of the earth, the upper portion of the borehole being lined with a conventional surface casing **14** cemented in as shown at **16**. Suspended within the borehole is a drill string including a bit **18**, a drill collar **20** connecting the bit to one or more sections of drill pipe **22**, and a Kelly bar **24** arranged to rotate the drill pipe, and which in turn is supported for rotation by a swivel **26** carried by a travelling block **28** of a conventional drilling rig. The rig comprises a conventional derrick **30**, a power unit or draw-works **32**, a rotary table including bevel gearing **33**, for gripping and rotating the Kelly bar, and a drilling fluid pump **34**. The pump has an intake **35** extending into and receiving drilling fluid from a sump **36** and a discharge through a surge chamber to a pipe **38** through which the drilling fluid is delivered under pressure to the interior of the derrick and thence to the drill string by way of a flexible "rotary" hose **39** and the before-mentioned swivel **26**. The apparatus thus far enumerated, with the exception of drill collar **20**, may be of conventional design and are shown to illustrate the environment of the instant invention and to aid in a clear explanation of the operation of the system of the invention. The drilling fluid received by pump **34** from sump **36** through intake **35** is forced into pipe **38** past or through surge chamber **37**, which acts to greatly decrease the relatively high frequency fluctuations in pressure in pipe **38** resulting from the inherent delivery characteristics of the pump, which customarily is of the positive displacement, constant speed type. The drilling fluid is thus pumped or forced in conventional manner downwardly in a stream through the passage within the hollow drill string, and is discharged from the lower end of the drill string through suitable holes in the drill bit, and returns to the top of the borehole through the annular space surrounding the drill string. At the top of the borehole the casing **14** is provided with a side discharge pipe **40** leading to sump **36**, from which sump, after settling, the drilling fluid is withdrawn for reuse as before-described. The pressure drop in the drilling fluid stream between the pump and the holes in the drill bit provides a pressure-difference between selected points or locations in the drill collar, which pressure difference may be employed in a novel manner in the system of the invention.

Referring now to Figures 2*a* and 2*b*, drill collar **20** extends downwardly from drill pipe **22** to drill bit **18** and is attached to those elements by conventional threaded joints **21** and **23**, respectively. Snugly fitted within the lower end of the smooth bore **42** of collar **20** is an instrument spool **43** arranged to support an instrument case in a manner hereinafter more fully described. This spool is held in fixed position in bore **42** by suitable means, such as internal lock rings or set screws **44** threaded through the wall of the drill collar **20** and engaging a suitable annular groove **44***a* in the exterior face of the lower flange of the instrument spool. Sealing means, such as an elastic ring **46***a* mounted in a suitable annular recess **46** in the lower flange of the instrument spool **43** are employed to seal off an annular space **47** between the drill collar and the instrument spool from entry of drilling fluid. At its upper end spool **43** is provided with a plurality of radially extending legs **48** snugly fitting bore **42**, and a smooth end face provided with an annular groove **49** containing an annular sealing ring **49***a*. Situated immediately above spool **43** in bore **42** of the drill collar is a lower drilling fluid pressure sensing means or device, comprising an internally recessed barrel member **50**, to the inside of which at its lower end is secured a snugly fitting internal sleeve or tube **51** provided with a number of perforations or holes **52**. Tube **51** has a smoothly surfaced exterior face adapted to coact with respective sealing rings **53** and **54** of a suitable elastomer such as "neoprene," contained in suitable internal annular grooves in barrel member **50**. The sealing rings are adapted to prevent leakage of drilling fluid through the passages or holes provided for set screws **55** which serve to secure the perforate tube **51** within the barrel member **50**. The internal configuration of barrel **50** is such as to provide an internal annular groove or recess of sufficient length to span all of the before-mentioned holes **52** in tube **51** and thus to form, with tube **51**, an elongate annular cavity **56**. The exposed internal surface of tube **51** is thus arranged and adapted to form a portion of the boundary of the drilling fluid stream passage extending through the drill collar there-adjacent, and accordingly the cavity **56** serves to sense or "receive" through holes **52** the pressure in the drilling fluid stream at that point or location within the drill collar. The lower end of barrel member **50** is provided with a smooth, radially extending end face adapted to coact with sealing ring **49***a* in the before-mentioned annular groove **49** and is provided with a similar, radially extending upper end face provided with an annular groove **57** arranged for the reception of a sealing ring **57***a*. Barrel member **50** is preferably concentrically positioned within drill collar **20**, by means of a series of integral, radially extending legs **58** and **59** arranged in circumferentially spaced-apart positions around the lower and upper end portions, respectively, of the barrel member and snugly fitting the interior wall of bore **42** of the drill collar.

Situated in the drill collar immediately above barrel member **50** is a hydraulic apparatus-supporting spool **60** (Figure 2*a*) having flanged ends each carrying a series of radially extending, circumferentially spaced apart legs **61** and **62**, respectively, by means of which the spool is concentrically positioned within bore **42** of the drill collar. The lower flange of spool **60** is provided with a smooth radial end face coacting with the before-mentioned sealing ring **57***a* contained in annular groove **57**, and the upper end face of spool **60** is provided with an annular groove **63** in which is seated a sealing ring **63***a*, as indicated.

Situated immediately above spool **60**, in bore **42** of the drill collar, is a drilling fluid flow resistance varying means or device comprising an internally recessed barrel member **64** having secured therein a flexible and preferably elastic member or sleeve **65** as by means of pinch rings **66** and **67** secured in turn to the inside of the opposite ends of the barrel member **64** by means of suitable screws as indicated at **67***a*. Barrel member **64** is provided with an internal annular recess closed on its interior by sleeve **65** and providing between the exterior surface of sleeve **65** and the interior surface of the barrel member an elongate annular space or cavity **68** for a purpose hereinafter described. The inner surface of the flexible sleeve **65** is exposed to the drilling fluid stream and forms a portion of the boundary of the drilling fluid stream flowing through the drill collar.

Annular space 68 is effectively sealed from the drilling fluid stream by the pinching action of pinch rings 66 and 67 on respective ends of flexible sleeve 65. Suitably secured to the internal face of pinch ring 67, as by means of welded circumferentially spaced-apart radial vanes 69, is a strong metal core means preferably in the form of a strong steel tube 70 positioned preferably concentrically within and extending throughout the full length of the exposed portion of the interior of sleeve 65. Tube 70 serves as a central passage to limit the degree of closure of the sleeve 65 and to by-pass a portion of the drilling fluid stream passing therethrough, and tube 70 is of such external diameter as to provide an annular space 71 between the exterior of tube 70 and the interior of sleeve 65, through which another portion of the drilling fluid stream normally flows when sleeve 65 is in normal position or attitude. Barrel 64 is concentrically positioned in bore 42 of the drill collar by means of upper and lower series of radially extending, circumferentially spaced-apart legs 72 and 73, respectively, which may be formed as integral parts of the barrel and are shaped to provide a snug fit within bore 42 of the drill collar. Upper pinch ring 67 is provided with a smooth radial end face with an annular sealing ring groove 74 therein.

Situated in bore 42 immediately above the flow resistance varying device is an upper pressure sensing or "receiving" device comprising an internally recessed or grooved barrel 75 having secured therein in snug fitting relationship a perforated metal tube 76 provided with a plurality of perforations 77 all leading laterally from the bore of the tube 76 into an annular cavity or space 78 formed between the exterior wall of tube 76 and the interior surface of barrel 75. Tube 76 serves as a screen to exclude from connected apparatus coarse drill chips or other foreign bodies, and is securely positioned within the interior of barrel 75 in a manner similar to that previously described with respect to tube 51 and barrel 50 of the lower or downstream pressure sensing device. Barrel 75 is concentrically positioned in bore 42 of the drill collar, at its lower end by a series of radially extending, circumferentially spaced-apart legs 79, and at its upper end by an annular flange 80 formed to snugly fit within the bore 42. The lower end of barrel 75 is provided with a smooth radial and face adapted to coact in sealing relation with a flexible sealing ring 74*a* situated in the aforementioned annular groove 74. Flange 80 of barrel 75 is equipped with a peripheral groove 81 in which is mounted an elastic sealing ring 81*a* adapted to coact with the smooth wall of bore 42. The upper radial end face of flange 80 is provided with an annular recess in which is seated an elastic sealing ring 82. Sealing ring 82 is adapted to be compressed, as indicated, when drill collar 20 is screwed at threads 21 onto drill pipe 22, and together with the previously mentioned sealing rings is adapted to effectively seal the space lying between the several barrels and spools and the interior wall of the drill collar from entry of drilling fluid. Drilling fluid has access to cavity 78 through the aforementioned perforations 77, hence the device is effective to act to receive or sense the static pressure of the drilling fluid stream therewithin in a manner similar to that hereinbefore explained with reference to the lower pressure sensing or receiving device.

From the foregoing description of the structure encased within the drill collar 20, it will be seen that there is provided a central passage through which the drilling fluid is forced to flow in a stream from drill pipe 22 to drill bit 18. It is further apparent that the upstream pressure within the drilling fluid stream at a point within tube 76 of the upper pressure receiving device may be determined by gauging the like pressure in the confined annular space or cavity 78, and that the pressure there apparent may be transmitted or translated to a distant point such as that within the cavity 68 for utilization at that point, by hydraulically connecting the latter with space 78 as by means of a hydraulic conduit, the pressure transmission in the preferred embodiment occurring by actual flow or transfer of drilling fluid from space 78 to cavity 68 through the hydraulic conduit connection. The same considerations apply with respect to the lower pressure receiving device or means, wherein the pressure of the drilling fluid in the stream within tube 51 is available for transmission from the annular cavity 56 which communicates directly with the interior of tube 51 through holes or perforations 52. Since by reason of the inherent frictional losses occuring within a fluid stream flowing in a closed conduit, a pressure gradient exists along the stream, the pressure sensed at the upper pressure receiving device or means, within cavity 78, is greater than that in the drilling fluid stream in the annular space 71 bounded by the resilient sleeve 65, and the pressure sensed within the cavity 56 in the lower pressure sensing device or means is lower than that at either of the mentioned upstream points, it being noted that the drilling fluid stream flows downwardly from drill pipe 22 to bit 18 in the direction indicated by the several arrows in the drill collar.

It thus is seen that there is provided a first or upper pressure sensing or receiving device at one location or point in the drilling fluid stream, a second or lower pressure receiving means at a second location or point, and a drilling fluid flow-changing means or device at a location between said points, each of said pressure sensing or receiving means being arranged to encircle the drilling fluid stream or form a portion of the boundary thereof.

The sealed space lying outside the several spools and barrels but within bore 42 of the drill collar is utilized to house apparatus, as will be hereinafter more fully described, and is preferably filled with a suitable pressure compensating hydraulic fluid or oil, whereby the relatively high external pressure of the drilling fluid may be equalized or neutralized. To allow the pressure of the pressure compensating fluid surrounding the several barrels and spools to remain approximately equal at all times to that of the drilling fluid, regardless of pressure and temperature variations in the latter, there is provided a sealed flexible bellows 84 (Figure 2*a*) suitably mounted on spool 60, and having its inside communicating with the drilling fluid stream by means of a tube 85.

It is evident that a considerable portion of the drilling fluid flowing through the drill collar will normally flow through the annular space 71 between tube 70 and sleeve 65, and that this portion of the drilling fluid flow may be restricted or completely closed off by inward flexure of sleeve 65 from the attitude or position depicted in Figure 2*a*. Thus, if sleeve 65 were inwardly flexed into contact with the exterior surface of tube 70, the drilling fluid flow through the annular space 71 would be shut off, and thus the flow restricted to that through the bore of tube 70. Any such restriction of drilling fluid flow is reflected in a pressure rise in the drilling fluid upstream from sleeve 65. It is evident that inward flexure of sleeve 65 may be effected by application to the exterior surface thereof, that is, in annular cavity 63 surrounding sleeve 65, of a pressure greater than that in the drilling fluid stream within the annular space 71. Thus, it is seen that if space 78 in the upper pressure-sensing device is hydraulically connected with the annular cavity or space 68 surrounding sleeve 65, as by means of a suitable conduit, flow of drilling fluid will occur, from the space 78 to the annular space 68, by virtue of the before-mentioned pressure differential therebetween, and this action will result in inward flexure or diametral contraction of sleeve 65 with the consequent creation of both a further pressure rise in the drilling fluid upstream from sleeve 65, and a pressure drop within the sleeve 65 due to the increased velocity of flow of the fluid through the thus restricted passage, which still further increases the before-mentioned pressure differential between spaces 78 and 68.

If, following this, the annular space 68 is hydraulically connected with space 56 of the lower pressure sensing device downstream from space 68, drilling fluid will then be exhausted from space 68 to space 56 by virtue of the pressure differential therebetween, and thereby permit outward flexure or diametral expansion of sleeve 65. The outward flexure of sleeve 65 is enhanced if the sleeve is formed of resilient material, such as a synthetic rubber of tough and elastic quality; hence in the preferred embodiment of the invention, said sleeve is formed of resilient material.

It is found that as soon as inward flexure or contraction of sleeve 65 is commenced, a hydraulic action not unlike that of a Venturi meter is initiated, in which, as the stream cross-section is reduced, the drilling fluid velocity within the sleeve is increased with a resultant corresponding reduction in pressure in that region, which action is hereinafter termed a "venturi action." Under the influence of the described action, the pressure differential between space 68 and the interior of sleeve 65 is increased as hereinbefore mentioned and sleeve 65 thus tends to continue to flex inwardly automatically and without further increase of external pressure, kinetic energy from the drilling fluid stream being absorbed or used in the flexure of sleeve 65 in the process. With ordinarily employed drilling fluid flow rates and pressures, the unrestrained inward flexing or contraction of sleeve 65 would quickly result in a rapid, complete, inward collapse of the sleeve and complete closing of the drilling fluid passageway, and possibly rupture of the sleeve. Such complete collapse is undesirable and is, in the illustrated embodiment of the invention, prevented, by means such as tube 70 positioned inside the sleeve, as hereinbefore described.

In the apparatus illustrated in Figures 2*a* and 3*b*, drilling fluid pressure sensed at space 78 may be controllably transferred to the exterior surface of the flow restricting sleeve 65 by movement of drilling fluid through hydraulic tubing 90, a preferably electromagnetically operated three-way control valve 91, and tubing 92, to cause the sleeve 65 to contract and thereby produce in the drilling fluid stream upstream therefrom a controlled pressure rise. This hydraulic connection may be more easily traced by reference to the hydraulic circuit diagrams of Figures 3*a* and 3*b* which represent schematically the hydraulic connections and other apparatus depicted in Figures 2*a* and 2*b*, and from which figures it will be evident that the noted pressure transfer can occur only when valve 91 is actuated by energization of its magnet or solenoid 150 as depicted in Fig. 3*b*. By means of valve 91, control over the time and extent of inward flexing of sleeve 65 may be effected, as will be later more fully explained.

It will be noted that when inward flexing of sleeve 65 occurs, flow of the stream of drilling fluid therethrough is restricted, the extent of the restriction being limited by tube 70 and by the time period during which the pressure sensed at cavity 78 is applied to the exterior of sleeve 65. The result of any such restriction is the initiation and propagation of a pressure rise in the drilling fluid stream above sleeve 65, which pressure rise travels through the drilling fluid stream to the top of the bore-hole and is there detected and recorded in a manner to be presently explained. Pressure increases of the type thus produced are employed for signaling, as has been previously mentioned. To make the pressure rise into a repeatable pressure-change signal, it is only necessary to remove the restriction imposed by sleeve 65 after a sharp pressure rise has been produced, whereupon another pressure rise can be produced. To induce return movement of the previously flexed or contracted sleeve 65 to its normally expanded condition, it is only necessary to reduce the pressure outside that sleeve to a value at or below the pressure existing at the time in the stream within the sleeve 65. This is accomplished with the pressure-change signal producing apparatus depicted in Figures 2*a* and 2*b* by return movement of valve 91 to the deenergized position indicated in Figure 3*a*, whereby valve 91 then connects the space 68 outside of sleeve 65 through a suitable conduit means such as tubing 95, to the downstream cavity 56, where there exists a pressure lower than that within sleeve 65 and space 68. Drilling fluid is then exhausted from space 68 around sleeve 65 through tubing 92, valve 91, and tubing 95, to cavity 56 from whence it returns to the drilling fluid stream within tube 51 through the before-mentioned holes 52, thereby permitting sleeve 65 to expand to normal diameter. Return flexure of sleeve 65 to the normal attitude or diameter as just described and as shown in Figures 2*a* and 3*a* is aided, in the illustrated embodiment of the invention, by the natural elasticity of the sleeve 65.

From the above, it is clear that a pressure-rise signal may be initiated and propagated in the drilling fluid stream above sleeve 65 by supplying a pulse of electric current to the solenoid 150 of the solenoid-operated valve 91, the result being actuation of the valve to cause the temporary connection of cavity 78 to cavity 68 in turn resulting in inward flexing of sleeve 65; followed by deenergization of the solenoid and return of valve 91 to normal position under the influence of the valve spring as indicated in Figure 3*a* to connect cavity 68 to lower cavity 56, and the consequent return of sleeve 65 to normal diameter. While there may thus be propagated a controlled fluid pressure-change signal comprising a complete cycle of pressure rise and fall to normal pressure, it is sufficient for some purposes for only the pressure rise to be propagated, and hence in this specification and the claims to follow, the terms "flow change," "pressure rise," "pressure change" and derivations thereof, are intended to relate equally well to either type of pressure change signal propagation in the fluid stream, that is, either a pressure rise, a pressure decrease, a pressure rise followed by a pressure drop, or a pressure drop followed by a pressure rise. As indicated in Figures 2*a*, 2*b*, 3*a* and 3*b*, electric current pulses may be supplied to the solenoid 150 of valve 91 via insulated conductors 98 and 99 which extend through sealing grommets in the case of the magnet portion of valve 91 and extend on to information-obtaining apparatus contained on the instrument spool 43 and indicated generally by reference numeral 100 in Figure 2*b*. Referring again to Figures 3*a* and 3*b*, operation of the apparatus through successive pressure-change cycles will be explained, it being noted that the flow of drilling fluid through the collar 20 is from top to bottom in those figures, as indicated by the arrows within the bores of the members there depicted, and it being noted that there is a pressure gradient along the drilling fluid stream from top to bottom thereof as shown in the drawing. Cavities 78, 68 and 56 and the tubing and valve ports and passages interconnecting them are assumed to be full of drilling fluid. Upon receipt from the information obtaining apparatus 100 of a pulse of electric current by the solenoid 150 of control valve 91, the valve is opened or actuated to the opened position indicated in Figure 3*b* to permit flow of drilling fluid from cavity 78 through tubing 90, valve 91, and tubing 92 into cavity 68 under the influence of the aforementioned pressure gradient. Sleeve 65 is thereby caused to flex or contract inwardly to a drilling fluid stream flow-restricting position such as that indicated in Figure 3*b*. The inward flexure or contraction of sleeve 65 initiated by the action of the drilling fluid pressure thus translated to its exterior, continues until further inward movement of the sleeve is prevented by tube 70, and this results, due to the resultant restriction of flow of drilling fluid therethrough, in a pressure-rise in the drilling fluid upstream from the sleeve 65. Upon cessation of the pulse of electric current through the solenoid 150 of the valve 91, the valve returns to the position as shown in Figure 3*a* under the influence of spring 149, thereby cutting off transmisssion of pressure from the upper pressure-sensing

device cavity 78 to sleeve 65 and connecting the space surrounding the sleeve 65 to cavity 56 of the downstream pressure-sensing device, in which latter cavity the pressure, already below that at either sleeve 65 or the upper pressure-sensing device, may have been further lowered to some extent by the restriction of flow of drilling fluid through the flow-restricting sleeve 65. Drilling fluid is then exhausted from cavity 68 through tubing 92, valve 91, and tubing 95 into downstream cavity 56, and therefrom through holes 52 into the drilling fluid stream. This action is accompanied by outward flexure or expansion of sleeve 65 to normal position. Such return of sleeve 65 to normal position again allows unrestricted flow of drilling fluid, whereupon the pressure rise above sleeve 65 disappears, and the pressure gradient through the several parts of the apparatus again assumes a normal value.

If it is desired to limit the magnitude of the pressure-rise signal to a value less than its maximum, it is only necessary to limit the duration of each of the electric current pulses to a period insufficient to allow complete inward flexure of sleeve 65 so that cavity 68 is connected to cavity 56 before complete inward flexure of sleeve 65 is accomplished. Thus, it is evident that the duration of a pressure-rise signal may be regulated by corresponding regulation of the length or duration of the electric current pulse passed through the solenoid portion of the valve 91. Hence, the apparatus may be employed to transmit information via pressure-change signals to the surface from within the borehole, using any suitable coding system connected to the solenoid 150.

Referring to Figure 2*a*, the solenoid valve 91 is suitably mounted upon the exterior surface of instrument spool 60 by means of suitable binding bands 120 and 121 passed around the outside of the valve and encircling the barrel of spool 60. The hydraulic conduits or tubing 90, 92 and 95, serving to connect the two pressure-sensing devices and the drilling fluid stream flow-restricting device with valve 91, readily extend between those several units through spaces between the radially extending legs on the various barrels and the instrument spool, as indicated in Figure 2*a*. While in the preferred embodiment of the invention as illustrated, the space between the interior wall of the drill collar bore 42 and the aforementioned barrels and instrument spool 60 is filled with a suitable hydraulic liquid such as oil, this space may conveniently be filled under certain operating conditions with a suitable solid or semi-solid medium providing any desired degree of mechanical support for the tubing and other components. In the case of liquid, provision is made for expansion and contraction of the liquid by bellows 84.

Referring again to Figures 1, 2*a* and 2*b*, the exterior of drill collar 20 has applied thereto, as by cementing or vulcanization, a jacket or layer 122 of rubber or other suitable material arranged to insulate electrically a considerable length of the drill collar. Mounted under tension upon jacket 122 and surrounding the drill collar is a ring electrode 123 to which is secured an electric conductor 124 passing through an insulation grommet 125 mounted in a suitable threaded hole in the drill collar wall and connecting electrode 123 to an internal contact 126 mounted flush in bore 42 of the drill collar. Contact 126 is arranged for electrical coaction with a spring brush 127 suitably mounted on an insulating grommet 128 carried upon the leading into the interior of a case 130 arranged to house the instrumentalities and connections of the information-obtaining apparatus 100. Apparatus 100 is provided with a ground conductor 131 passing out of case 130 through a grommet 132 electrically grounding the apparatus to the earth by way of a grounding screw secured in a suitable hole in the lower flange of instrument spool 43 as indicated. Thus, it will be noted that bit 18 and the lower exposed portion of drill collar 20, which are electrically connected together at their threaded juncture 23 and electrically connected to instrument spool 43 by metallic contact therewith, are arranged to act as a lower electrode of the information-obtaining apparatus. Ring electrode 123 forms the other electrode of the information-obtaining apparatus. The information-obtaining apparatus, which per se forms no part of the present invention and may be constructed like those disclosed in the patents to Silverman 2,354,887 and Arps 2,524,031, is depicted generally in Figure 2*b*. The information-obtaining apparatus indicated generally at 100 has output leads 132*a* and 132*b* extending to and electrically connected with a conventional two-conductor socket 138 mounted on case 130 and into which the plug ends of the aforementioned conductors 98 and 99 are secured. By these means electrical current output pulses produced by the information-obtaining apparatus, and representing desired information, are transmitted or conveyed to the solenoid 150 of valve 91.

Valve 91, which acts in the manner hereinbefore described when supplied with electric current signal pulses, may be of any suitable and conventional construction. As illustrated in Figures 3*a* and 3*b*, it comprises a non-magnetic and smoothly bored cylindrical valve body 142 provided with first, second and third spaced ports 143, 144 and 145, respectively, in which conduits 90, 92 and 95 are respectively secured in any suitable manner as, for example, by brazing. Slidably mounted in the bore of the valve body 142 is a smoothly fitting valve core 148 which is urged toward a closed or exhaust position by a compression spring 149 acting between one end of the valve core and the opposed inner end wall of the valve solenoid 150 which is suitably secured to the valve body as by being screwed thereon or press fitted and soldered, as indicated. The ferromagnetic solenoid armature 151 is secured to the valve core 148 as by being threaded into a suitable tapped hole in the latter and is arranged to move the valve core from the exhaust position indicated in Figure 3*a* to the inlet position indicated in Figure 3*b*, with attendant compression of spring 149, in response to energization of the solenoid winding by an electric current. Valve core 148 may be provided with annular grooves and cooperating elastic sealing rings 152, 153 adjacent its ends to exclude drilling fluid from the space adjacent the valve ends, and may be provided with a longitudinal duct 154 extending from end to end thereof as indicated to provide free flow of fluid for balance of pressure on the opposite ends of the valve core. If desired, this space may be filled with oil.

It will be noted from the preceding description that only such electrical energy as is used by the information-obtaining apparatus and the relatively small amount used by the solenoid of valve 91 need be supplied by electric power means contained within the drill collar, the relatively large amount of power required for producing pressure-change signals being in other than electrical form and entirely furnished directly by the drilling fluid stream as before-described. Since the information-obtaining means usually requires but a small amount of electric power, and the power consumption of the solenoid of the valve is intermittent and of very low value (of the order of a fraction of a watt), only a small and inexpensive battery or electric power source need be carried in the drill collar. Such a small and inexpensive battery is indicated in Figure 2*b* as comprising a circumferentially arranged series of individual cells, two of which are shown at 166 and 167, electrically interconnected in suitable fashion and housed in casing 130 and supplying electric current to the information-obtaining apparatus through suitable leads 168 and 169.

Signals in the form of a pressure change, or a plurality thereof, propagated in the stream of drilling fluid in the drill collar as before-described, are detected at the top of the borehole by a conventional pressure transducer unit 170 shown in Figure 1, which operates to translate pressure-change signals in the drilling fluid stream within

pipe 38, to which the transducer is hydraulically connected as indicated, into corresponding electric signals. The transducer output electric signal is applied by suitable conductors to a conventional amplifier and electrical filter unit 171 to which power is supplied from a suitable source such as a battery 172. The output of the amplifier and filter unit is fed to a conventional graphic recorder unit 175 via conductors 173, 174. The recorder has a pen, indicated at 176, arranged to produce a trace 177 on a moving strip of paper 178, the trace indicating the amplitude and duration of the variations in the electrical signal output of unit 171, which in turn are correspondingly indicative of the variations in pressure in pipe 38 and are thus indicative of the information obtained in the borehole. The graph paper is moved past pen 176 by a suitable mechanism including gearing housed in a case 179 forming a part of the recorder unit, which gearing may be actuated by a clockwork or as shown by a cable 180 coursing over guide pulleys 181 and 182, the cable having an end secured by suitable means to traveling block 28 of the drilling rig. The thus generally described elements serving to translate and log the pressure-change signals received in pipe 38 in correlation with the position of bit 18 in the borehole or with respect to time are conventional and well known in the art. They may, for example, be similar to those shown and described in the aforementioned Arps Patent No. 2,524,031.

Referring now to Figures 4, 5*a* and 5*b*, which depict transverse sectional views showing a modification of the by-pass tube 70 in the drilling fluid flow restricting device, a modified form of structure is depicted for regulating the action and extent of the inward flexure of flexible sleeve 65. This modification of core or tube 70 may be employed to give extended service life to flexible sleeve 65 under extremely severe operating conditions. The modified type of drilling fluid by-pass tube member 70*a* preferably is given the form of a core of two-lobed cross-section and having a central by-pass passage or bore 70*b* extending therethrough from end to end, and having two opposed, substantially planar external faces 70*c* and 70*d* between which and the interior wall of flexible sleeve 65 is provided an outer pair of drilling fluid stream flow passages 71*a*, 71*b*, adapted to be closed or partially closed by inward flexing of sleeve 65, whereby to restrict the flow of drilling fluid to the central passage 70*b* and produce a pressure rise in the drilling fluid upstream from sleeve 65. Figure 5*a* illustrates this modified form of by-pass tube with sleeve 65 in the normal or non-flow-restricting attitude, and Figure 5*b* illustrates a cross-sectional view of the modified form of by-pass tube in sleeve 65 when the latter is in inwardly flexed, flow-restricting position. It will be noted from an examination of Figure 5*b* that sleeve 65, due to its thickness and its elastic nature, tends not to fully close against core 70*a* and thus leaves open a plurality of drilling fluid passages 70*e* adjacent each intersection of its planar faces with the curved portions of its outer perimeter. Passages 70*e* permit or allow a continuous flow of drilling fluid through the interior of inwardly flexed sleeve 65, which flow eliminates any tendency toward fluttering or rapid partial opening and partial closing of sleeve 65 against tube 70*a*, which could occur under certain circumstances if complete closure of sleeve 65 against core 70*a* were effected. Thus this form of by-pass tube may be used where it is desired to transmit long pressure-rise signals where fluttering might occur and where operating conditions are extremely severe. In Figure 4 there is indicated the manner in which by-pass tube 70*a* is secured within flexible sleeve 65. By-pass tube 70*a* has its external perimeter formed with the same radius as the internal radius of pinch ring 67, and accordingly provides a snug fit between the two elements along the curved portion of the perimeter of core 70*a*. Along the curved upper edges of the planar upper end face of core 70*a*, the core is welded to the interior of pinch ring 67, as indicated in Figure 4. Additionally, core 70*a* is supported in concentric position within elastic sleeve 65 by its base or lower end resting upon a shelf 70*f* (Fig. 4) formed by the upper end face of lower pinch ring 66, the internal diameter of which is, for the purpose, made slightly less than that of pinch ring 67.

Referring now to Figures 6, 7*a* and 7*b*, there is shown a modified form of drilling fluid by-pass tube or core means 70*m* having a longitudinal by-pass bore 70*n* therethrough end to end and having a plurality of longitudinally extending lobes 70*p*, the outer surfaces of which form segments of a circle of a diameter equal to the internal diameter of upper pinch ring 67, and the upper ends of which lobes are brazed or welded to the internal bore of that pinch ring as indicated in Figure 6. The external surfaces of by-pass tube 70*m* between the aforementioned lobes are formed with longitudinally extending, concave channels having radii approximately equal to the internal radius of sleeve 65 and are preferably, but not necessarily, each provided with a longitudinally extending drilling fluid by-pass slot 70*q*, or a plurality thereof, whereby, when sleeve 65 is flexed inwardly in contact with tube 70*n*, as indicated in Figure 7*b*, there are provided a plurality of drilling fluid flow passages between the elastic sleeve 65 and the core member thereby obviating fluttering of the flow-restricting sleeve during transmission of long signal pulses. Since flow of drilling fluid through the restricted passage formed by the slot 70*q* is at a higher velocity than that in the stream thereabove, the pressure is decreased which aids in holding sleeve 65 firmly against the tube. Since the external concave surfaces of the core 70*m* are of a radius substantially equal to the internal radius of the flexible sleeve 65, as beforementioned, the latter is subjected to a minimum of distortion and stress when flexed inwardly into contact with the core member. This latter action is illustrated in the cross-sectional view of Figure 7*b*. Since elastic sleeve 65 is distorted but little when used in conjunction with the form of core just described, it is adapted to have a maximum service life.

From a consideration of the above description considered in conjunction with the drawings, it will be noted that the invention provides a simple, durable means of extracting and utilizing energy directly from a moving body of drilling fluid in a drill string in an earth well borehole to produce one or more signaling flow resistance or pressure changes in the fluid stream within or adjacent the bottom of the drill string for transmission through the drilling fluid stream to the surface of the earth, the pressure changes being representative of desired information obtained at or adjacent the lower end of the drill string.

While the aforementioned objects of the invention are accomplished by the disclosed specific embodiments of the invention, it is apparent that various modifications and variations of the described system and of its parts may be made without departing from the invention, as defined by the appended claims. For example, information other than that secured by electrode means may be transmitted, it being necessary only that the information be supplied to the valve solenoid in the form of an electric current or one or more pulses of electric current, which are significant of the information to be converted into corresponding fluid flow restrictions. Also, variations in the form and assembly of the pressure-sensing and flow-restricting means may be effected. For example, the pressure-sensing means could readily take the form of piston means or Sylphon bellows communicating with the drilling fluid stream at the proper points and connected hydraulically or mechanically to the flow-restricting means. Also, while for purposes of clarity and ease of illustration the pressure sensing devices and flow resistance means have been shown in closely spaced rela-

tionship, they may, in practice, be spaced apart along the drilling fluid stream any suitable distance; and they may readily be positioned in another element of the drill string rather than in the drill collar.

While in the preferred embodiment of the invention herein disclosed and explained, a change in the resistance to flow of fluid resulting in a pressure change or a flow change in the drilling fluid stream, or both, is created by contraction of a flexible tubular member encircling the drilling fluid stream, it will be evident that the invention equally well applies to means wherein such pressure or flow change is created by flexure of a flexible member or movement of a movable member which only partially encircles the drilling fluid stream or merely protrudes in proper manner into the stream, or which is itself encircled by the stream and is flexed or moved outwardly to restrict the stream to produce a pressure rise or inwardly to create a pressure drop. Also, means producing the converse of such actions is envisioned. Accordingly, it is not desired to limit the broad aspects of the invention to the specific details of the described embodiments thereof.

What is claimed is:

1. In a system adapted for logging boreholes while being drilled by means including a drill string having a fluid filled passage extending longitudinally therethrough and means for forcing the fluid to flow down through said passage in said drill string, the combination comprising: a drill string having such fluid passage; signaling means therein including variable fluid flow resistance means fixed in said drill string in the vicinity of the lower end thereof, actuatable by application of fluid pressure thereto to effect a variation in resistance to flow of said fluid therethrough to produce a flow-change signal in fluid in said passage; sensing means to pick up pressure of said fluid in said passage at a point spaced from said flow resistance means; control means in communication with said sensing means and actuatable to apply said pressure to and to withdraw said pressure from said variable fluid flow resistance means thereby to actuate said fluid flow resistance means to vary the said resistance to flow of said fluid; and means responsive to a physical condition in said borehole to actuate said control means to cause said variable flow resistance means to produce in said fluid a flow-change signal representing said physical condition.

2. A system as defined by claim 1 in which said fluid flow resistance means comprises a flexible member at least partially encircling a portion of said passage and arranged to be flexed into a fluid stream flowing therethrough.

3. A system as defined in claim 1 in which said fluid flow resistance means comprises a resilient member at least partially encircling a portion of said passage in said drill string and arranged to be flexed into a fluid stream flowing therethrough; and in which said control means includes a valve and means including conduit means relatively connecting said valve with said sensing means and said variable fluid flow resistance means.

4. In a system for logging boreholes while being drilled by means including a drill string having a fluid passage extending longitudinally therethrough and means for forcing fluid to flow down through said passage in said drill string, the combination comprising: a drill string having such fluid passage; flow-change signal producing means including variable fluid flow resistance means in said drill string in the vicinity of the lower end thereof actuatable by application of fluid pressure thereto to effect a change of resistance to flow of said fluid therethrough to produce a flow-change signal in said fluid in said passage; sensing means to pick up pressure of said fluid in said passage at a point spaced upstream from said flow resistance means; and signal control means in communication with said sensing means and actuatable to apply said pressure to and to withdraw said pressure from said variable fluid flow resistance means thereby to actuate said flow resistance means to increase and decrease, respectively, the said resistance to flow of said fluid, to produce a controlled flow-change signal in said fluid.

5. In a system for logging boreholes while being drilled by means including a drill string having a fluid passage extending longitudinally therethrough and means for forcing a stream of fluid to flow down through said passage in said drill string, the combination comprising: a drill string having such fluid passage; signaling means including variable fluid flow resistance means in said drill string in the vicinity of the lower end thereof actuatable by application of fluid pressure thereto to effect a variation of resistance to flow of said fluid therethrough to produce a flow-change signal in said stream of fluid in said passage; sensing means to pick up the pressure of said fluid in said passage at a point spaced downstream from said flow resistance means; and signal control means in communication with said sensing means and actuatable to apply said pressure to and to withdraw said pressure from said variable fluid flow resistance means thereby to actuate said flow resistance means to decrease and increase, respectively, the said resistance to flow of said fluid, to produce a controlled flow-change signal in said stream.

6. In a system for logging boreholes while being drilled by means including a drill string having a fluid passage extending longitudinally therethrough and means for forcing a stream of fluid to flow down through said passage in said drill string, the combination comprising: a drill string having such fluid passage; signaling means including variable fluid flow resistance means in said drill string in the vicinity of the lower end thereof actuatable by application of variable fluid pressure thereto to effect a variable resistance to flow of said fluid therethrough to produce a flow-change signal in said stream of fluid in said passage; a first sensing means to pick up pressure of said fluid in said passage at a point spaced upstream from said fluid flow resistance means, and a second sensing means to pick up pressure of said fluid in said passage at a point downstream from said fluid flow resistance means; and signal control means in communication with said first and second sensing means and actuatable to apply said pressure from said first sensing means to said variable fluid flow resistance means while said pressure from said second sensing means is removed therefrom, and to apply said pressure from said second sensing means to said variable fluid flow means while said pressure from said first sensing means is removed therefrom, thereby to actuate said fluid flow resistance means to increase and to decrease, respectively, the said resistance to flow of said fluid, to produce a controlled flow-change signal in said stream.

7. A system according to claim 1, including means to receive and translate the flow-change signal into a sense-perceptible signal.

8. A system according to claim 6, including means to receive and translate the flow-change signal into a sense-perceptible signal.

9. In a logging system for an earth borehole being drilled by means including a hollow drill string having a passage through which a drilling fluid stream flows under pressure successively past upstream and downstream points therein, and in which system information to be logged is transmitted by pressure-change signals in and through said drilling fluid stream, in combination: a drill string having such fluid passage, and a drilling fluid stream therein; signaling means including a resilient tubular member encircling the drilling fluid stream between said points and effective when flexed to produce a pressure-change in said drilling fluid stream and thereby propagate a pressure-change signal in the drilling fluid stream; means including information obtaining means, acting to produce an output representative of obtained information; and means including pressure-change signal control means receiving said output, and acting in response to said output first to translate the pressure at

one of said points to the outside of said resilient tubular member to cause flexure thereof, and thereafter acting to translate the pressure at the other of said points to the outside of said resilient tubular member to induce return flexure thereof to normal position, to propagate a pressure-change signal representative of said obtained information in said drilling fluid stream for transmission thereby and therethrough.

10. A system according to claim 9, including means to receive and translate the pressure-change signal into a sense perceptible signal.

11. A system according to claim 9, including a by-pass core means inside said resilient tubular member to limit inward flexure of the latter; and means to receive and translate the pressure-change signal.

References Cited in the file of this patent

UNITED STATES PATENTS

994,168	Koppitz	June 6, 1911
1,764,790	Hook et al.	June 17, 1930
2,353,143	Bryant	July 11, 1944
2,388,141	Harrington	Oct. 30, 1945
2,517,820	Aagaard	Aug. 8, 1950
2,524,031	Arps	Oct. 3, 1950
2,587,188	McFadden	Feb. 26, 1952
2,590,215	Sausa	Mar. 25, 1952
2,598,307	Rutgers	May 27, 1952
2,700,131	Otis et al.	Jan. 18, 1955

FOREIGN PATENTS

182,656	Great Britain	July 13, 1922