324-374 SR SEARCH ROOM

OR 3,379,965

April 23, 1968 D. R. TANGUY ET AL 3,379,965

APPARATUS FOR INVESTIGATING EARTH FORMATIONS INCLUDING A FLEXIBLE PAD MEMBER HAVING AN INVESTIGATING MEANS AND LONGITUDINALLY EXTENDIBLE HINGING MEANS FOR ROTATING PORTIONS OF THE PAD MEMBER

Original Filed June 4, 1965 3 Sheets-Sheet 1

Fig. 1

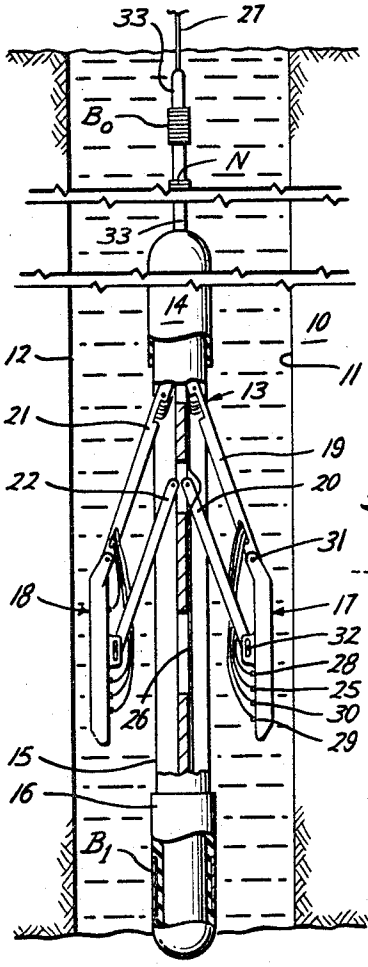
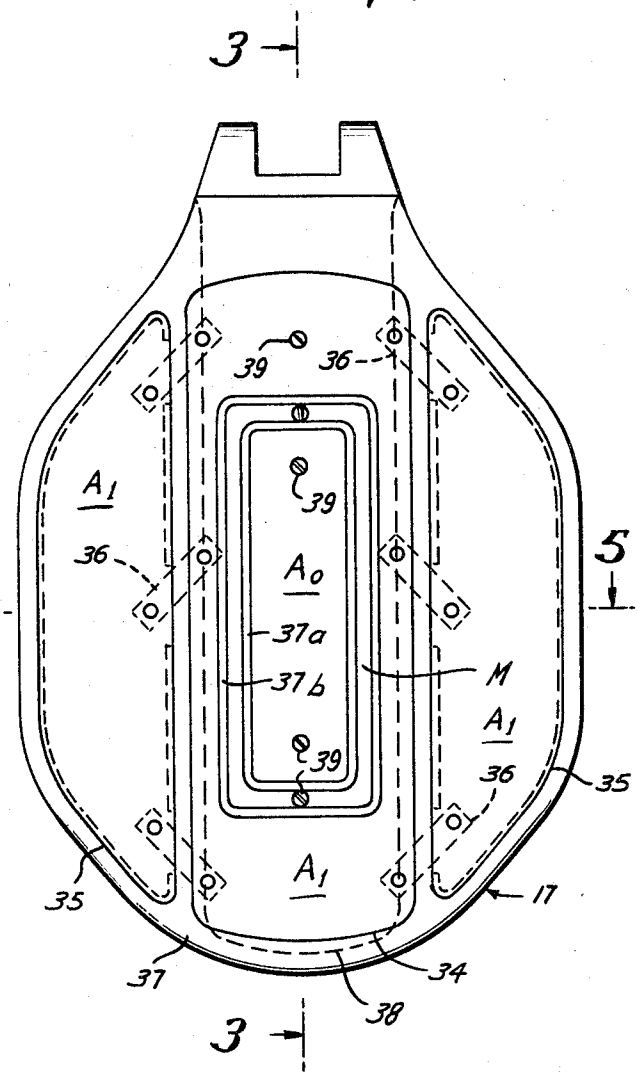


Fig. 2



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APPARATUS FOR INVESTIGATING EARTH FORMATIONS INCLUDING A FLEXIBLE PAD MEMBER HAVING AN INVESTIGATING MEANS AND LONGITUDINALLY EXTENDIBLE HINGING MEANS FOR ROTATING PORTIONS OF THE PAD MEMBER

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Fig. 3

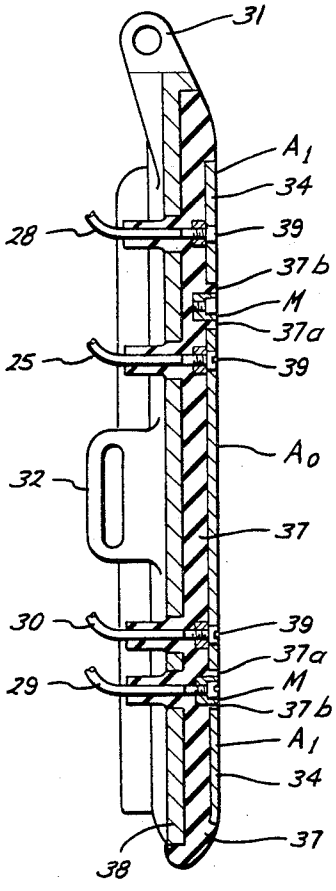
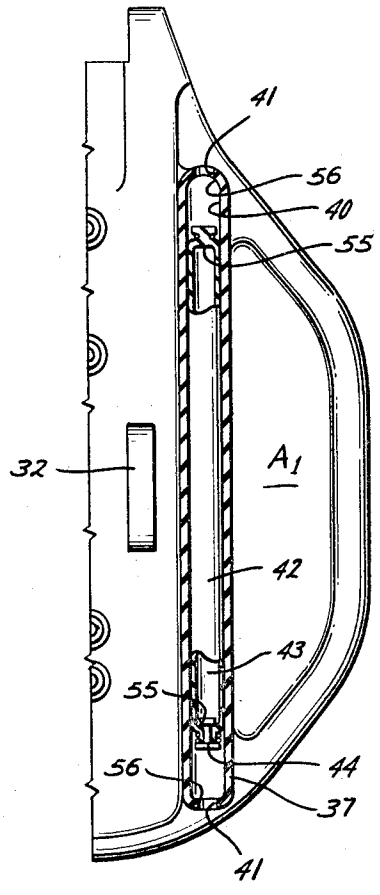


Fig. 4



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Fig. 5

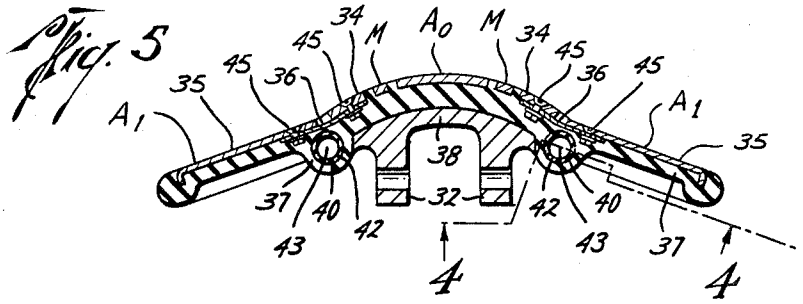
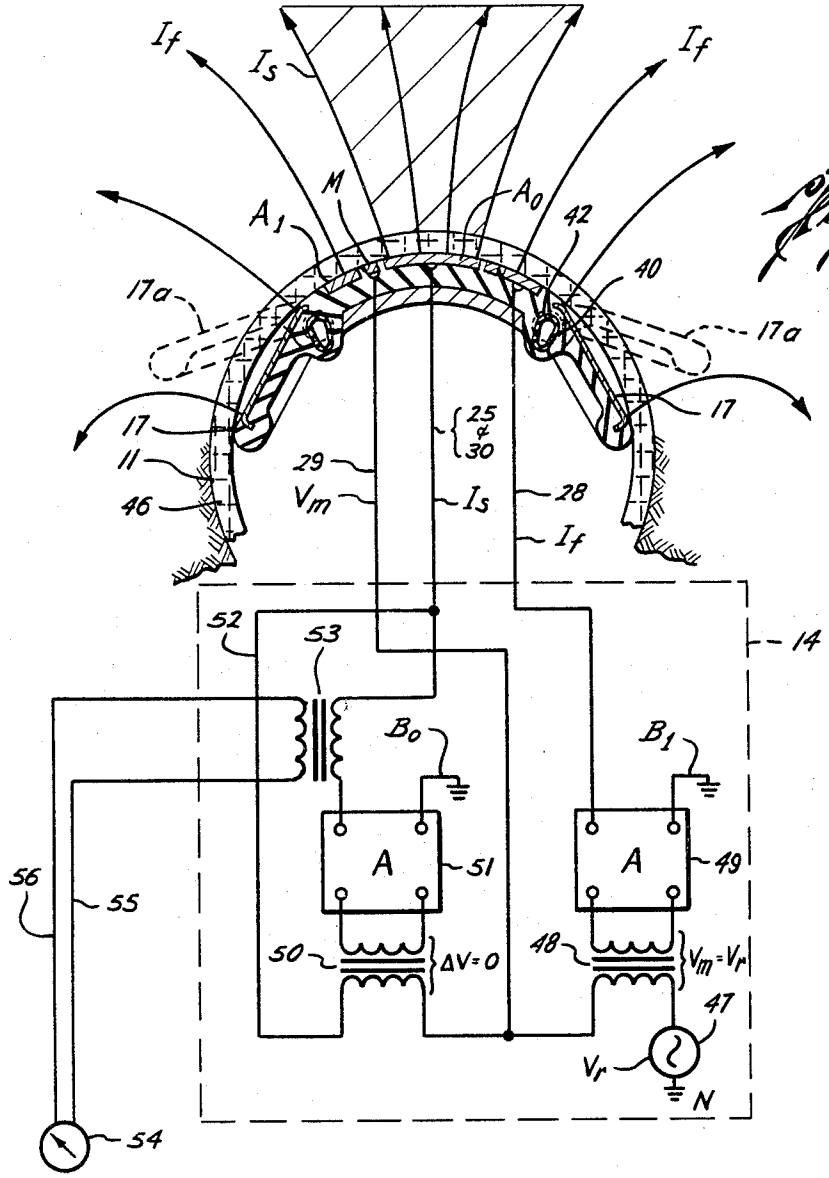


Fig. 6



United States Patent Office 3,379,965 Patented Apr. 23, 1968

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APPARATUS FOR INVESTIGATING EARTH FORMATIONS INCLUDING A FLEXIBLE PAD MEMBER HAVING AN INVESTIGATING MEANS AND LONGITUDINALLY EXTENDIBLE HINGING MEANS FOR ROTATING PORTIONS OF THE PAD MEMBER

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Continuation of application Ser. No. 461,392, June 4, 1965. This application June 28, 1967, Ser. No. 649,746
14 Claims. (Cl. 324—10)

ABSTRACT OF THE DISCLOSURE

In accordance with an illustrative embodiment of the invention, a wall-engaging pad member having earth formation exploring means is constructed in a manner that adjacent portions of the pad member can bend with respect to the central portion thereof. To accomplish this, a fluid-filled bladder is situated in a hollow chamber located between the different portions of the pad member. This fluid-filled bladder acts to maintain the adjacent pad portions in an outward position with respect to the central pad portion, but is displaceable in response to force being applied to the adjacent pad portions so that the pad member as a whole may more nearly conform to the radius of curvature of the borehole wall.

This is a continuation of application Ser. No. 461,392 filed June 4, 1965, now abandoned.

This invention relates to electrical apparatus for investigating subsurface earth formations traversed by a borehole and, more particularly, to apparatus for measuring the electrical resistance properties of a subsurface earth formation by means of electrodes in the borehole adapted to be pressed against the borehole wall.

One method of investigating subsurface earth formations traversed by a borehole is to move a system of pad mounted wall-engaging electrodes through the borehole and determine the resistance presented by the earth formations to the flow of electrical current emitted from one or more of the electrodes. The electrical record or log obtained from this manner of investigation aids in determining the nature and lithological character of the various subsurface earth formations. The resulting data is useful in the case of oil well boreholes in that, among other things, it enables the presence and depth of any oil or gas bearing strata to be determined.

In drilling a borehole by the usual rotary method, the borehole is filled with a drilling mud during the drilling process. This drilling mud will penetrate radially into the subsurface earth formations for a distance dependent upon the porosity of the earth formations. When the drilling mud invades a permeable strata, there is a mudcake remaining on the wall of the borehole. This mudcake is caused by the solid particles of drilling mud being unable to pass through the permeable strata. The mud filtrate which actually invades the permeable zone alters the electrical resistance properties of the earth formation immediately adjacent to the borehole wall and, not uncommonly, increases the resistance of such portions, particularly where fresh muds are used. However, the resistivity of the mud cake which is formed on the borehole wall is usually relatively low compared to the resistivity of the flushed zone.

For the case of pad mounted electrodes which engage the wall of the borehole, as the mudcake thickness increases, more and more of the electrode current is short

circuited back to the borehole current return point by the relative low resistance path formed by the mudcake. This makes the measurements of the flushed zone resistivity and thus, any subsequent formation porosity determination more difficult, because the measurement is influenced to a large degree by the mudcake resistivity. This problem is overcome to a large extent by using a wall-engaging electrode system of the focused type. Systems of this type are to be found in U.S. Patent No. 2,712,629, granted to H. G. Doll on July 5, 1955, and in U.S. Patent No. 3,132,298, granted to H. G. Doll and J. L. Dumanoir on May 5. 1964. In a wall-engaging electrode system of the focused type, a current flow is emitted by one of the electrodes and used for determining or surveying the formation resistance characteristics. This surveying current flow is constrained to a desired lateral flow pattern by a focusing current emitted by another one of the electrodes which is adjacent to the main surveying electrode. Focusing current emitted by means of the focusing current electrodes opposes any tendency of the survey current to flow in an undesired direction, as for example, along the mudcake. Thus, most of the survey current is caused to penetrate laterally into the earth formations for some appreciable distance. As indicated by the Doll and Dumanoir patent, more elaborate precautions are required as the environment becomes more severe or the requirements on the measurements become more demanding.

The electrode system described in the Doll and Dumanoir patent provides an improved measurement of the resistivity of the invaded zone region of the earth formations even for a case of relatively thick mudcake. Among other things, this is accomplished by utilizing relatively large electrode surfaces on the wall-engaging pad member. It has been found to be especially desirable to extend the focusing electrode outward in a circumferential direction around the borehole on both sides of the central survey electrode. It has been found, however, that in some boreholes, undesired variations appear in the measurements. After considerable effort, it has been found that the undesired variations in these instances are caused primarily by relatively large changes or variations of the shape or contour of the borehole wall. If the cross-sectional shape of the borehole remains fairly circular and the diameter fairly constant, results are satisfactory. If, however, a section of the borehole assumes an elliptical or other non-circular shape and if, at the same time, a fairly thick mud-cake is present on the borehole wall, then the measured value will be somewhat different depending upon what side of the ellipse is being engaged by the electrode system.

It has been found that this undesired effect can be largely eliminated if a constant relationship can be maintained between the curvature of the borehole wall and the curvature of the wall-engaging face of the electrodes. This requires providing different electrode system curvatures for the different sides of the ellipse, depending upon which side of the ellipse the electrode system is pressed against.

The relationship between the formation resistivity and the measurement made with an electrode system is described by the formula:

$$R = K \cdot \frac{V}{I}$$

where R is the formation resistivity, K is a proportionality constant or calibration constant depending upon the geometry of the electrode array including the size and shape of the individual electrodes and the distance between the electrodes, V the voltage at one of the electrodes, and I the current emitted by one of the electrodes. Either the voltage may be kept constant and current

variations measured, or the current kept constant and the voltage variations measured. The curvature of the electrode device is a factor in determining the K coefficient in the above formula. Therefore, changes in the electrode system curvature will tend to introduce corresponding changes into the measured values. Since these changes are independent of the formation resistivity, they are undesirable.

It is an object of the present invention therefore, to provide new and improved apparatus for measuring electrical resistance properties of subsurface earth formations adjacent to a borehole.

It is another object of the present invention to provide new and improved wall-contact electrode apparatus of the focused type which provides improved focusing action under adverse borehole conditions.

It is a further object of the present invention to provide a new and improved focused type wall-contact electrode system which can adapt itself to excessive variations in radius of curvature of the borehole wall.

It is an additional object of the invention to provide a new and improved focused type wall-contact electrode system which can adapt itself to excessive changes in the curvature of the borehole wall without introducing excessive changes in the calibration constant of the system.

In accordance with the present invention, apparatus for investigating earth formations comprises a flexible pad member having an exploring means for investigating the earth formations and adapted to be pressed against a borehole wall, the pad member having a relatively stiff central portion carrying part of the exploring means. The pad member also has a relatively stiff portion adjacent to the central portion and carrying another part of the exploring means. The pad member additionally has a hinging means, including fluid-filled displaceable means longitudinally disposed between the central and adjacent pad portion for rotating the adjacent pad portion with respect to the central pad portion for enabling the flexible pad member to more nearly conform to the curvature of the borehole wall.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, the scope of the invention being pointed out in the appended claims.

Referring to the drawings:

FIG. 1 illustrates, partially in cross-section, a representative embodiment of borehole investigating apparatus constructed in accordance with the present invention;

FIG. 2 is an enlarged front view of the wall-engaging face of one of the electrode pads of the FIG. 1 apparatus;

FIG. 3 is a cross-sectional view of the electrode pad of FIG. 2 taken along the section line 3—3 thereof;

FIG. 4 is a partial cross-sectional view of the electrode pad of FIG. 2 taken along the section line 4—4 of FIG. 5 showing a hinging means therein; and

FIG. 5 is a cross-sectional view of the electrode pad of FIG. 2 taken along the section line 5—5 thereof; and

FIG. 6 is a typical cross-sectional view of the electrode pad of FIG. 2, the electrode pad being disposed in a borehole with current flow lines indicated therein, and an electrical schematic of the circuitry of the present invention.

Referring to FIG. 1 of the drawings, there is shown a representative embodiment of a downhole portion of an apparatus constructed in accordance with the present invention for investigating a formation **10** traversed by a borehole **11**, the borehole **11** being filled with a conductive fluid or drilling mud **12**. This apparatus includes an elongated support member **13** adapted for movement through the borehole **11**. The support member **13** includes an upper instrument housing portion **14** of a generally cylindrical shape having a hollow fluid-tight interior for enclosing certain downhole electrical circuits to be discussed hereinafter. The support member **13** also includes an intermediate frame or chassis portion **15** in the form of an iron or steel I-beam or equivalent structure and a lower nose portion **16** of a generally cylindrical shape.

Supported from an intermediate I-beam portion **15** of the support member **13** on opposite sides thereof are a pair of electrode pad members **17** and **18**, each of which is adapted to be urged against the wall of the borehole **11**. The pad member **17** is supported by way of support arms **19** and **20**, which are pivotally coupled to the pad member **17** and the I-beam portion **15**. Similarly, pad member **18** is supported by way of support arms **21** and **22**, which are pivoted to both the pad member **18** and I-beam portion **15**. A suitable actuating mechanism for extending and retracting support arms **19** and **21** is included within the lower portion of the instrument housing section **14**.

The downhole portion of the apparatus also includes a current return electrode B_1 located on the support member **13** close enough to the location of the pad member **17** so as to be electrically proximate thereto, but longitudinally spaced apart from the location of the pad member **17** so that no portion of this B_1 electrode is located directly behind the pad member **17**. This B_1 current reture electrode is of generally cylindrical shape and is mounted on suitable electrical insulation material which either covers or forms the nose portion **16** of support member **13**. Electrical connection to the B_1 current return electrode is made by way of an insulated conductor **26** which extends upwardly along the I-beam portion **15** to the instrument housing **14**.

The downhole support member **13** is suspended in the borehole **11** by way of an armored multi-conductor cable **27** which extends upwardly to a suitable drum and winch mechanism (not shown), located at the surface of the earth for raising and lowering the support member **13**. The first hundred feet or so of the cable **27** immediately above the instrument housing portion **14** is covered with a layer of electrical insulation material **33** such as rubber. Supported on this layer of insulation material **33** towards the upper end thereof are an electrically remote current return electrde B_0 and an electrically remote potential reference electrode N.

The electrical connections to electrodes A_1, M, and A_0 are made by way of insulated conductors **25**, **28**, **29** and **30**. These insulated conductors **25**, **28**, **29** and **30** pass upwardly through the hollow interior of the support arm **19** to the electrical circuits contained within the instrument housing portion **14**, or if support arm **19** is not hollow, as for example, a channel shaped member, then conductors **25**, **28**, **29** and **30** are secured to support arm **19** to pass upwardly to instrument housing portion **14**. Mechanical connections of the electrode pad member **17** to the support arms **19** and **20** is made by way of lug members **31** and **32** respectively. The electrical continuity of the lug members **31** and **32** may be broken by means of non-conductive inserts.

Only the electrode pad member **17** will be dealt with in the explanation of this invention. The pad member **18** can be any downhole testing apparatus, the particular apparatus not being a feature of this invention.

Considering the electrode pad member **17**, the FIG. 2 view of electrode pad member **17** shows the face portion of the pad that is pressed against the borehole wall. The major portion of the face of pad member **17** is formed by a focusing electrode A_1, which forms most of the outer portion of pad member **17**. Focusing electrode A_1 has a non-flexible main central portion **34** and non-flexible adjacent wing portions **35** immediately adjacent to and on opposite sides of main central portion **34**. Both portions of focusing electrode A_1 are made of a suitable electrically conductive material, such as iron. The main central portion **34** and adjacent wing portions **35** of focusing electrode A_1 are connected together by a series

of flexible metal braids **36** (shown as dotted lines) to provide electrical continuity between the portions of focusing electrode A_1. The flexible metal braids **36** are riveted to portions **34** and **35** of focusing electrode A_1.

The electrode pad member **17** also includes an elongated non-flexible electrode A_0 of rectangular shape centrally located inside of central portion **34** of focusing electrode A_1. Electrode A_0 constitutes a survey current electrode for emitting survey current into the adjacent earth formations. Located intermediate of survey electrode A_0 and focusing electrode A_1 is a non-flexible potential monitor electrode M. This potential monitor electrode M has an exposed surface portion of narrow width which defines a path encircling the A_0 survey electrode. Electrodes A_0, M and A_1 are embedded in a suitable insulation material **37** such as rubber. Insulation material **37** has a portion **37***a* encircling survey electrode A_0 which insulates survey electrode A_0 from potential monitor electrode M, and a portion **37***b* between potential monitor electrode M and central portion **34** of focusing electrode A_1 which insulates potential monitor electrode M from focusing electrode A_1. The electrodes A_0, M and A_1 are bonded in place during the molding process.

Referring now to FIG. 3, there is shown a cross-sectional view of electrode pad member **17** taken along the section line 3—3 of FIG. 2. Survey electrode A_0 of pad member **17** is centrally located with respect to the other electrodes of pad member **17** and is embedded in rubber insulation material **37**. The survey electrode A_0 is made of a non-flexible conductive material, such as iron. Adjacent to survey electrode A_0 on both sides thereof is the monitor electrode M, also made of a non-flexible conductive material, such as iron. On the upper and lower part of the electrode portion of electrode pad member **17** and adjacent to monitor electrode M is central portion **34** of focusing electrode A_1, also made of a non-flexible conductive material, such as iron.

Also embedded in insulation material **37** on the opposite side of pad **17** from the electrodes is a support plate **38**. Forming a part of support plate **38** are lug members **31** and **32**, to which support arms **19** and **20** are attached (see FIG. 1). Conductors **25**, **28**, **29** and **30** are embedded in insulation material **37** and connected to electrodes A_0, M and central portion **34** of A_1 by screws **39**. All of the metal members of electrode pad member **17** are bonded in insulation material **37** during the molding process.

Looking now at FIG. 4, there is shown a partial cross-sectional view showing a cutaway view of the hinging means of pad **17**. Insulation material **37** has a cylindrical hollow chamber **40** formed therein and running longitudinally through pad member **17** and located between non-flexible portions **34** and **35** of focusing electrode A_1 and at a fixed distance from the wall-engaging face of electrode pad member **17**. Located on both ends of the cylindrical hollow chamber **40** are circular passageways **41** formed in insulation material **37**. Circular passageways **41** are open to the outside of pad member **17** and thus provide access to cylindrical hollow chamber **40** within insulation material **37**.

Located within cylindrical hollow chamber **40** is a bladder or sack **42** made of an elastic material, such as rubber. Bladder **42** is filled with a suitable fluid **43** having a low temperature coefficient as, for example, silicone oil. As an alternative, cylindrical hollow chamber **40** could be filled with certain materials in place of bladder **42**, such as very soft rubber or plastic. One end **55** of bladder **42** has a metal insert **44** placed in an opening in bladder **42**. Metal insert **44** may be removed to enable removing the fluid **43** located within bladder **42** through circular passageway **41**. There is sufficient space left on both sides of bladder **42** within cylindrical hollow chamber **40** to allow bladder **42** to stretch outwardly in both directions. The force of fluid **43** within bladder **42** maintains the ends of bladder **42** approximately equal distance from the ends **56** of cylindrical hollow chamber **40**. The bladder **42** located within cylindrical hollow chamber **40** is also located on the other side of pad member **17** in the same location between portions **34** and **35** of focusing electrode A_1, that is, pad member **17** is symmetrical as concerns the fluid-filled bladder **42** located within cylindrical hollow chamber **40** shown in FIG. 4.

Looking now at FIG. 5, there is shown a cross-sectional view of pad member **17** taken along cross-section line 5—5 of FIG. 2. Electrodes A_0, M and A_1 are shown located on the wall-engaging face of pad member **17**. Flexible metal braids **36** are connected to the non-flexible electrode portions **34** and **35** of focusing electrode A_1 by rivets **45**, shown on both sides of survey and monitor electrodes A_0 and M. Metal braid members **36** provide electrical continuity between electrode portions **34** and **35** of focusing electrode A_1 and still allow for bending between non-flexible electrode portions **34** and **35**. The ends of non-flexible electrode portions **35** are turned down at the ends and embedded in insulation material **37**, except where flexible metal braids **36** are connected. Located intermediate of and below non-flexible electrode portions **34** and **35** of focusing electrode A_1 on both sides of pad member **17** are bladders **42** located within cylindrical hollow chamber **40** and filled with fluid **43**. The metal support member **38** of which lug members **32** form a part thereof is shown embedded in insulation material **37**. It can be seen that insulation material **37** insulates the electrodes A_0, M and A_1 from one another, while at the same time, holding these electrodes along with the other items of pad member **17** in place within pad member **17**.

Looking now at FIG. 6, there is shown a typical cross-sectional view of pad member **17** pressed against a mudcake **46** lining the borehole wall **11**. There is shown a representative electrical schematic associated with pad member **17** and the current flow lines emanating into the earth strata surrounding the borehole from pad member **17**.

Turning now to the schematic diagram portion of FIG. 6, the circuit portion contained within the dash line box **14** corresponds to the circuit portions that are located within the interior of the instrument housing portion **14** of FIG. 1. The electrical connections to the electrodes on pad member **17** are shown in FIG. 3, but represented in FIG. 6 as conductors touching electrodes A_o, M and A_1 for purposes of clarity of the electrical circuits.

The circuits are constructed to maintain the potential level V_m of the monitor electrode M very nearly constant with respect to a remote reference point and, at the same time, to determine the formation resistance characteristics by measuring the resulting variations in the magnitude of the survey current I_{ss} emitted from the central A_0 electrode. Alternating-current reference voltage V_r is supplied from source **47** by way of input transformer **48**, a high-gain amplifier **49**, and a conductor **28** to the A_1 focusing current electrode. Also supplied to the input transformer **48** of the amplifier **49** via conductor **29** is a signal representative of the potential, V_m, of the potential monitor electrode M. This potential signal V_m is supplied with like polarity to the side of the transformer **48** primary winding opposite from the reference voltage V_r, so that if the monitor electrode M is at a potential nearly equal to the reference V_r, then the net input signal to the amplifier **49** is nearly zero. If, on the other hand, the potential level V_m of the monitor electrode M differs from the V_r value, then the amplifier **49** input signal, which is supplied to the A_1 electrode so as to bring the monitor voltage V_m back to the desired V_r value. Thus, the potential level of the monitor electrode M is kept substantially constant with respect to the remote reference point represented by electrode N.

In addition, the potential difference between monitor electrode M and the A_0 survey current electrode is adjusted so as to be maintained at a value of substantially zero. To this end, the monitor electrode signal V_m is also supplied to an input transformer **50** of a high-gain ampli-

fier 57. A signal representative of the potential level of the A_0 electrode is supplied to the opposite side of the primary winding of the input transformer 50. This A_0 signal is supplied by way of conductor 52. Thus, if the M–A_0 potential difference is not substantially zero, then the error signal existing at the input of amplifier 51 serves to adjust the amplifier output current I_s which is supplied to the A_0 electrode by way of conductors 25 and 30 to establish this desired zero potential difference.

As the formation resistivity in front of the pad member 17 varies, different amounts of survey current I_s will be required to maintain the M–A_0 potential difference at a zero value. The magnitude of this survey current required will be directly proportional to the electrical conductivity of the formation material. This indication is transmitted to the surface of the earth by means of transformer 53 having a low impedance primary winding coupled in series between amplifier 51 and conductors 25 and 30 leading to the A_0 electrode. Thus, the voltage signal appearing across the secondary winding of transformer 53 is proportional to the I_s current flow and therefore to the formation conductivity. This voltage signal is transmitted to a galvanometer unit at the surface of the earth by way of cable conductors 55 and 56.

Instead of using the constant voltage circuit of FIG. 6, a constant current circuit such as shown in U.S. Patent No. 3,132,298, supra, could be used. As a further alternative, both the voltage and current may be varied and a suitable ratio circuit or device used for taking a ratio of voltage to current or vice versa for providing the desired output signal.

Electrode pad member 17 is shown pressed against a borehole wall 11 lined with a mudcake 46 in FIG. 6. The dotted line representation 17*a* of pad member 17 indicates the free space shape of pad member 17, that is, the shape of pad member 17 if there were no borehole wall. The solid line representation 17 indicates the shape of pad member 17 in the borehole when the radius of curvature of the borehole is less than the radius of curvature of pad member 17. It can be seen from FIG. 6 that the outer wing portions of pad member 17 which include non-flexible portion 35 of focusing electrode A_1 rotates about the cylindrical hollow chamber 40 for enabling the pad member 17 to more nearly conform to the radius of curvature of the borehole wall 11. The entire outer wing portions of pad member 17 on each side of the central portion of pad member 17, which wing portions each include the metal electrode portions 35 as well as the insulation material 37 behind electrode portions 35, must each rotate as a single non-flexible unit because of the structural non-flexibility that electrode portions 35 give to each wing portion. In addition, the central portion of pad member 17, which comprises the electrodes A_0, M, and portion 34 of A_1, insulation material 37, and the support plate 38 on the back of pad member 17, is a single non-flexible pad portion because of the structural non-flexibility of portion 34 of focusing electrode A_1. Thus, it can be seen that there are three non-flexible portions of pad member 17, i.e., one central portion and two adjacent wing portions. Located between the non-flexible central pad portion and each non-flexible adjacent pad portion are two hinging means, which include cylindrical hollow chamber 40, fluid-filled elastic bladder 42, flexible metal braids 36 and that portion of insulation material 37 immediately surrounding hollow chamber 40.

Since cylindrical hollow chamber 40 is hollow, the non-flexible adjacent wing portions of pad member 17, including electrode portions 35 of focusing electrode A_1 on both sides of pad member 17, are able to rotate about cylindrical hollow chamber 40 to a much greater extent than if this pivot point were solid rubber. Thus, by providing a hollow cylindrical portion running longitudinally with respect to the borehole through pad member 17 on both sides of central non-flexible portion 34 of focusing electrode A_1 and between non-flexible portions 35 thereof, the natural flexing action of the insulation material 37 is greatly enhanced and the non-flexible portions 35 of focusing electrode A_1 are able to rotate to a greater extent.

However, when pad member 17 is in a borehole with a larger radius of curvature than the radius of curvature of pad member 17, it is desirable for the non-flexible portions 35 of focusing electrode A_1 to be urged towards the borehole wall. However, cylindrical hollow chamber 40, while augmenting the flexibility of pad member 17, at the same time, decreases the ability of non-flexible electrode portions 35 of focusing electrode A_1 to spring back to the position shown as 17*a* in FIG. 6. It would be desirable therefore to provide a hollow chamber to augment the flexing ability of electrode pad member 17, while at the same time, providing a great degree of springing ability as if the hollow chamber were not present, so that pad member 17 will more nearly conform to the radius of curvature of the borehole wall when that radius of curvature is greater than the central non-flexible portion of electrode pad member 17.

Looking now at FIGS. 4 and 6 in conjunction, the fluid-filled bladder 42 does not extend to the ends 56 of cylindrical hollow chamber 40. When the radius of curvature of the borehole wall decreases, thus exerting pressure on the ends of non-flexible portions 35 of focusing electrode A_1, thus causing adjacent pad portions 35 to rotate, the cylindrical hollow chamber decreases in diameter, thus decreasing the unit volume thereof. The cylindrical hollow chamber 40 will take the non-cylindrical shape shown by the solid line representation of hollow chamber 40 in FIG. 6. This decrease in diameter of cylindrical recess 40 causes the fluid 43 within bladder 42 to press outwardly against the end portions 55 of bladder 42. This squeezing action on the fluid 43 within bladder 42, then, causes the bladder 42 to stretch outwardly towards the end portions 56 of hollow chamber 40. When the radius of curvature of that portion of borehole wall 11 that pad member 17 is pressed against begins increasing, the fluid-filled elastic bladder 42 tends to decrease in length causing the fluid 43 within bladder 42 to exert a pressure against the sides of hollow chamber 40 to force it back to its original cylindrical shape. This force against the sides of hollow chamber 40 causes the non-flexible adjacent wing portion 35 of focusing electrode A_1 to rotate towards the borehole wall. Thus, it can be seen that by placing a fluid-filled bladder 42 within a cylindrical hollow chamber 40, the ability of non-flexible adjacent wing portions 35 of focusing electrode A_1 to rotate in conformity with the radius of curvature of the borehole wall is greatly enhanced and, at the same time, the springing action is sufficient to force these non-flexible portions of focusing electrode A_1 against the borehole wall for a wide range of radius of curvatures of the borehole wall.

However, while the focusing electrode A_1 changes shape substantially in conformance with the shape of the borehole, it can be seen that the solid non-flexible portion of pad member 17, which includes electrodes A_0, M and non-flexible portion 34 of A_1, do not change shape and thus part of A_0 and M may be disposed at a small distance from the mudcake 46. It has been found, however, that it is not nearly as critical to have all of the survey electrode A_0 and the monitor electrode M in contact with the mudcake 46 as it is to have at least a part of focusing electrode A_1 on either side of survey electrode A_0 in contact or close proximity with the mudcake 46. When survey electrode A_0 is not in contact with the mudcake 46, the potential set up by focusing electrode A_1 will not allow the survey current emitted from survey electrode A_0 to diverge. On the other hand, when focusing electrode A_1 is at a distance from mudcake 46, the focusing current emitted therefrom will diverge rapidly back to the mudcake since there is no potential outside of focusing electrode A_1 to keep it from doing so.

Now concerning the focusing action of the present invention, there are seen current flow lines I_s and I_f in FIG. 6. Survey current electrode A_0 emits survey current I_s into the earth formation surrounding the borehole, which current diverges back to the current return electrode B_0 (see FIG. 1). The divergence of the survey current I_s back to the current return electrode B_0 becomes more severe when the mudcake **46** lining the borehole wall **11** is thick, in which case some of the survey current I_s will flow through the mudcake **46** to the current return electrode B_0. However, the focusing current I_f emitted from focusing current electrode A_1 directs the survey current I_s deeper into the earth formation by setting up a potential gradient concentrically surrounding survey current I_s, which maintains survey current I_s in a radial flow away from the borehole.

However, when the mudcake **46** is very thick and the borehole radius of curvature becomes non-uniform around the circumference of the borehole, a pad member of non-flexible construction could not conform to the radius of curvature of the borehole wall. If a pad member of non-flexible construction adapted for small radius of curvature boreholes were placed on that portion of the borehole wall where the radius of curvature of the borehole wall is greater than the radius of curvature of the pad member and the mudcake thickness fairly substantial, some of the focusing current I_f emitted from focusing electrode A_1 would tend to diverge more quickly back through the mudcake **46** to the mud-filled portion of the borehole proper. Thus, the survey current I_s emitted from survey electrode A_0 would also tend to diverge too quickly. On the other hand, when the radius of curvature of the borehole wall is less than that of a non-flexible pad member adapted for large radius of curvature boreholes, the survey electrode A_0 will be disposed at some great distance from the borehole wall since the focusing electrode portion of the pad member will contact the borehole wall first. In this event, the survey current emitted from survey electrode A_0 will have to travel through the mud **12** in the borehole **11** for an appreciable distance. Since the mud **12** may have a different resistivity than the resistivity of the surrounding earth formations the resistivity or conductivity measurements will be in error by an amount determined by the difference in resistivity of the mud with the surrounding earth formations and the distance that survey electrode A_0 is disposed from the borehole wall **11**.

However, with the flexible features of the present electrode pad member **17**, the survey electrode A_0 will always be pressed against the mudcake **46** lining the borehole wall **11** and the non-flexible outer portion **35** of focusing electrode A_1 will be rotated so that at least the end portion thereof will be in contact to the mudcake **46**. Thus, it can be seen that through the action of fluid-filled bladder **42** located within cylindrical hollow chamber **40**, the pad member **17** will more nearly conform to the radius of curvature of the borehole wall for very large variations in the radius of curvature of the borehole wall.

As seen by the current flow lines of FIG. 6, focusing current I_f emitted from focusing electrode A_1 extends laterally outward into the earth because the focusing electrode A_1 is in close proximity to the mudcake **46** lining the borehole wall **11**. Thus, there is very little divergence of the focusing current I_f emitted from points on the focusing electrode A_1 which are nearest to the survey electrode A_0, which in turn, extends the survey current I_s emitted from survey electrode A_0 laterally outward from the borehole for an appreciable distance. The focusing current I_f emitted from the end points of focusing electrode A_1 will tend to keep the focusing current I_f emitted from the points on focusing electrode A_1 closest to survey electrode A_0 extending laterally outward into the earth, which in turn, keeps the survey current I_s extending laterally outward into the earth. Thus, it can be seen that there is very little divergence of the survey current I_s under adverse borehole conditions and the accuracy of the resistivity or conductivity measurements will be improved under such conditions.

When the physical configuration of an electrode pad member is varied, the proportionality constant K of the device will vary. However, with the novel form of construction of electrode pad **17** shown in the present invention, there will be very little variation in the proportionality constant K. One reason for the small variation in the proportionality constant K is that the electrodes on the front side of pad member **17** are electrically insulated from the back side of electrode pad **17** by the insulation material **37**. Thus, because the front and back sides of electrode pad **17** are insulated from one another, a single value of proportionality constant K can be utilized in determining the resistivity or conductivity of adjoining earth formations over a wide range of radius of curvatures of the borehole.

While there have been described what are at present considered to be preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, intended to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. Apparatus for investigating earth formations traversed by a borehole comprising:

a flexible pad member having an electrode array and adapted to be pressed against a borehole wall, the pad member comprising:

(1) a non-flexible central portion having at least one electrode;

(2) non-flexible portions adjacent to the central portion and having at least a portion of one electrode; and

(3) hinging means, including fluid-filled chamber means, located within the flexible pad member for rotating the adjacent pad portions with respect to the central pad portion for enabling the flexible pad member to more nearly conform to the curvature of the borehole wall.

2. Apparatus for investigating earth formations traversed by a borehole comprising:

a flexible pad member having an electrode array and adapted to be pressed against a borehole wall, the pad member comprising:

(1) a non-flexible central portion having at least one electrode;

(2) non-flexible portions adjacent to the central portion and having at least a portion of one electrode; and

(3) hinging means, including fluid-filled chamber means, located within the flexible pad member and between the central pad portion and the adjacent pad portions for rotating the adjacent pad portions with respect to the central pad portion for enabling the flexible pad member to more nearly conform to the curvature of the borehole wall.

3. Apparatus for investigating earth formations traversed by a borehole comprising:

a flexible pad member having an electrode array and adapted to be pressed against a borehole wall, the pad member comprising:

(1) a non-flexible central portion having at least one electrode;

(2) non-flexible portions adjacent to the central portion on opposite sides thereof and having at least a portion of one electrode;

(3) two hinging means, each including fluid-filled chamber means, located within the flexible pad member, one hinging means located on each side of the central pad portion between the

central pad portion and each adjacent pad portion, for rotating the adjacent pad portions with respect to the central pad portion for enabling the flexible pad member to more nearly conform to the curvature of the borehole wall.

4. Apparatus for investigating earth formations traversed by a borehole comprising:

a flexible pad member having an electrode array and adapted to be pressed against a borehole wall, the pad member comprising:

(1) a non-flexible central portion having at least one electrode;

(2) non-flexible portions adjacent to the central portion and having at least a portion of one electrode; and

(3) hinging means, including fluid-filled chamber means, located within the flexible pad member between the central pad portion and each adjacent pad portion and at a fixed distance from the borehole wall-engaging face of the flexible electrode pad for rotating the adjacent pad portions with respect to the central pad portion for enabling the flexible pad member to more nearly conform to the curvature of the borehole wall.

5. Apparatus for investigating earth formations traversed by a borehole comprising:

a flexible pad member having an electrode array and adapted to be pressed against a borehole wall, the pad member having:

(1) a non-flexible central portion having at least one electrode;

(2) a non-flexible portion adjacent to the central portion and adapted to rotate about the central pad portion and having at least a portion of one electrode;

(3) a hollow chamber located within the flexible pad member for augmenting the rotation of the adjacent pad portion; and

(4) fluid-filled means located within the hollow chamber for urging the adjacent portion toward the borehole wall.

6. Apparatus for investigating earth formations traversed by a borehole comprising:

a flexible pad member having an electrode array and adapted to be pressed against a borehole wall, the pad member having:

(1) a non-flexible central portion having at least one electrode;

(2) a non-flexible portion adjacent to the central portion and adapted to rotate about the central pad portion and having at least a portion of one electrode;

(3) a hollow chamber located within the flexible pad member between the central pad portion and adjacent pad portion and at a fixed distance from the wall-engaging face of the electrode pad for augmenting the rotation of the adjacent pad portion; and

(4) fluid-filled elastic bladder means located within the hollow chamber for urging the adjacent pad portion toward the borehole wall.

7. Apparatus for investigating earth formations traversed by a borehole comprising:

a flexible pad member having an electrode array and adapted to be pressed against a borehole wall, the pad member having:

(1) a non-flexible central portion having a portion of a first electrode and at least one other electrode;

(2) a non-flexible portion adjacent to the central portion and adapted to rotate about the central pad portion and having a portion of the first electrode;

(3) a flexible metal member connecting the portions of the first electrode;

(4) a hollow chamber located within the flexible pad member between the central pad portion and adjacent pad portion and at a fixed distance from the wall-engaging face of the electrode pad for augmenting the rotation of the adjacent pad portion; and

(5) fluid-filled elastic bladder means located within the hollow chamber for urging the adjacent pad portion toward the borehole wall.

8. Apparatus for investigating earth formations traversed by a borehole comprising:

(a) a flexible pad member having an electrode array and adapted to be pressed against a borehole wall, the pad member having:

(1) a non-flexible central portion having at least one electrode;

(2) a non-flexible portion adjacent to the central portion and having at least one electrode;

(3) hinging means, including fluid-filled chamber means, located within the flexible pad member for rotating the adjacent pad portion with respect to the central pad portion for enabling the flexible pad member to more nearly conform to the curvature of the borehole wall;

(b) means for supplying a survey current to said at least one electrode within the central pad portion; and

(c) means for supplying a focusing current to said at least one electrode within the adjacent pad portion for maintaining the survey current in a radial direction from the borehole for a substantial distance.

9. Apparatus for investigating earth formations traversed by a borehole comprising:

a flexible pad member having an electrode array and adapted to be pressed against a borehole wall, the pad member having:

(1) a non-flexible central portion having at least one electrode;

(2) a non-flexible portion adjacent to the central portion and adapted to rotate about the central pad portion and having at least one electrode;

(3) a hollow chamber located within the flexible pad member between the central pad portion and adjacent pad portion and at a fixed distance from the wall-engaging face of the flexible pad member for augmenting the rotation of the adjacent pad portion; and

(4) fluid-filled elastic bladder means, located within the hollow chamber and filling only a portion thereof so that the elastic bladder means may expand upon rotation of the adjacent pad portion, for urging the adjacent pad portion toward the borehole wall.

10. Apparatus for investigating earth formations traversed by a borehole comprising:

(a) a flexible pad member having an electrode array and adapted to be pressed against a borehole wall, the pad member having:

(1) a non-flexible central portion having a portion of a first electrode and at least one other electrode;

(2) a non-flexible portion adjacent to the central portion and adapted to rotate about the central pad portion and having a portion of the first electrode;

(3) a hollow chamber located within the flexible pad member between the central pad portion and adjacent pad portion and at a fixed distance from the wall-engaging face of the flexible pad member for augmenting the rotation of the adjacent pad portion;

(4) fluid-filled elastic bladder means, located within the hollow chamber and filling only a portion thereof so that the elastic bladder means may expand upon rotation of the adjacent pad

portion, for urging the adjacent pad portion toward the borehole wall;

(5) a flexible metal member connected to the portions of the first electrode;

(b) means for supplying a survey current to said at least one other electrode within the central pad portion; and

(c) means for supplying a focusing current to said first electrode for maintaining the survey current in a radial direction from the borehole for a substantial distance.

11. Apparatus for investigating earth formations traversed by a borehole comprising:

a flexible pad member having exploring means for investigating earth formations and adapted to be pressed against the borehole wall, the pad member having:

(1) a relatively stiff central portion carrying part of the exploring means;

(2) a relatively stiff portion adjacent to the central portion and carrying another part of the exploring means; and

(3) hinging means including fluid-filled displaceable means longitudinally disposed between the central and adjacent pad portion, said displaceable means normally maintaining the curvature of said pad member at a given curvature but displaceable from its normal position upon force being applied to said adjacent portion to permit relative movement of the adjacent pad portion with respect to the central pad portion so that the pad member may more nearly conform to the curvature of a borehole wall.

12. The apparatus of claim **11** wherein the displaceable means is a fluid-filled bladder housed in a hollow chamber, the fluid-filled bladder being longitudinally displaceable in response to force applied on the adjacent pad portion to allow the adjacent pad portion to pivot with respect to the central pad portion.

13. Apparatus for inventigating earth formations traversed by a borehole comprising:

a flexible pad member having exploring means for investigating earth formations and adapted to be pressed against the borehole wall, the pad member having:

(1) a relatively stiff central portion carrying part of the exploring means;

(2) a relatively stiff portion adjacent to the central portion on one side thereof and carrying another part of the exploring means;

(3) a relatively stiff portion adjacent to the central portion on the other side thereof and carrying another part of the exploring means; and

(4) hinging means including fluid-filled displaceable means longitudinally disposed between the central and adjacent pad portions, said displaceable means normally maintaining the curvature of said pad member at a given curvature but displaceable from its normal position upon force being applied to said adjacent portion to permit relative movement of the adjacent pad portion with respect to the central pad portion so that the pad member may more nearly conform to the curvature of a borehole wall.

14. Apparatus for investigating earth formations traversed by a borehole comprising:

(a) a central support member adapted for movement through the borehole;

(b) a flexible pad member having exploring means for investigating earth formations and adapted to be pressed against the borehole wall, the pad member having:

(1) a relatively stiff central portion carrying part of the exploring means;

(2) a relatively stiff portion adjacent to the central portion and carrying another part of the exploring means;

(3) hinging means including fluid-filled displaceable means longitudinally disposed between the central and adjacent pad portion, said displaceable means normally maintaining the curvature of said pad member at a given curvature but displaceable from its normal position upon force being applied to said adjacent portion to permit relative movement of the adjacent pad portion with respect to the central pad portion so that the pad member may more nearly conform to the curvature of a borehole wall; and

(c) means movably connecting the relatively stiff pad portion to the central support member and adapted to urge the pad member against the borehole wall.

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