April 9, 1968 J. L. NEWMAN ETAL 3,377,549

COIL ASSEMBLY STRUCTURE AND MOUNTING FORMING AN ANNULAR CHAMBER TO BE MOUNTED AND SEALED ON A DRILL COLLAR

Filed Dec. 23, 1964

4 Sheets-Sheet 1

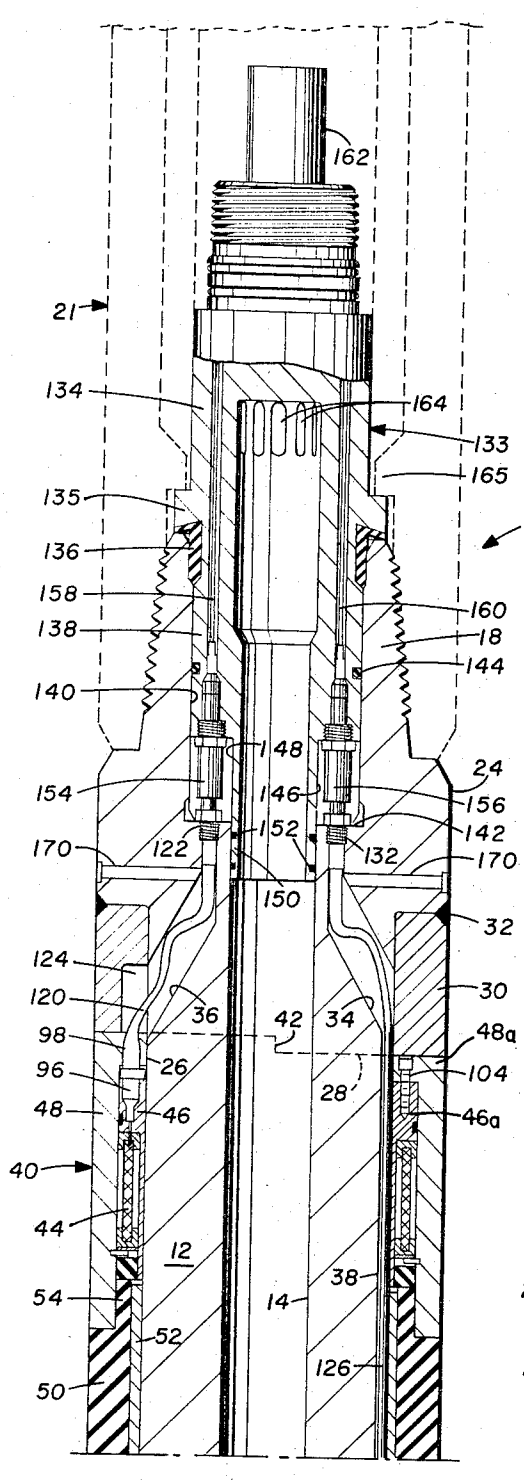


FIG. 1A

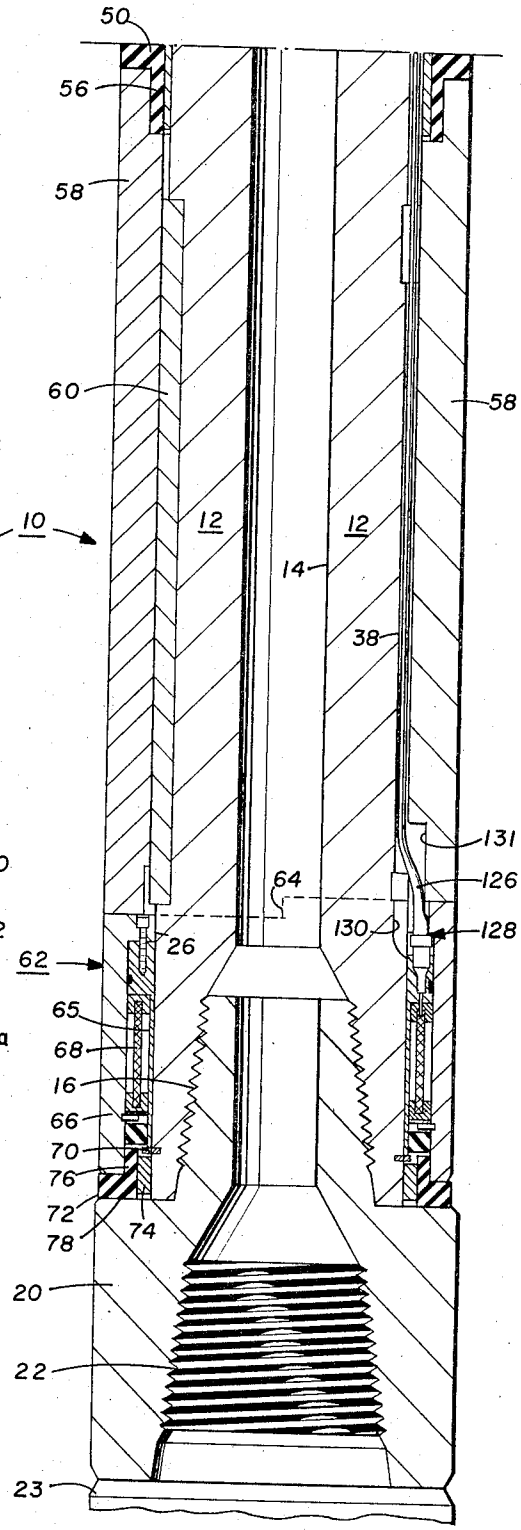


FIG. 1B

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COIL ASSEMBLY STRUCTURE AND MOUNTING FORMING AN ANNULAR CHAMBER TO BE MOUNTED AND SEALED ON A DRILL COLLAR

Filed Dec. 23, 1964 4 Sheets-Sheet 2

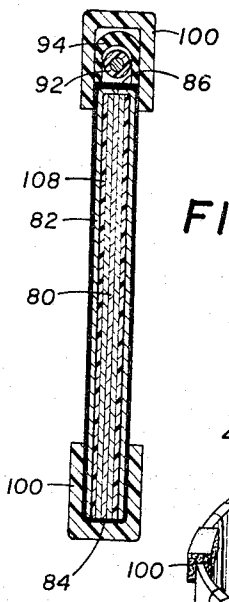


FIG. 4

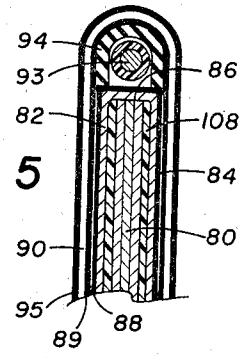


FIG. 5

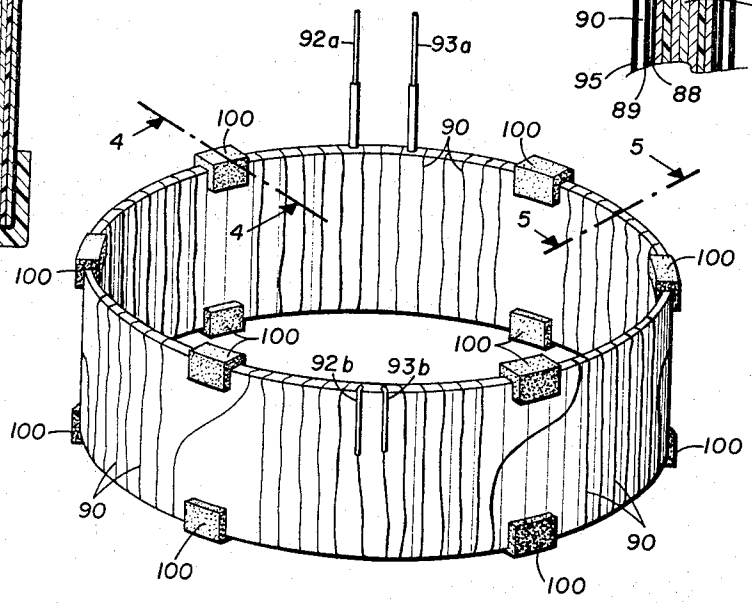


FIG. 2

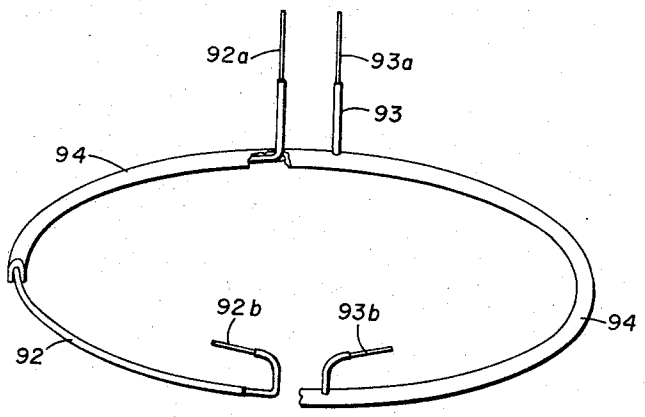


FIG. 3

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COIL ASSEMBLY STRUCTURE AND MOUNTING FORMING AN ANNULAR CHAMBER TO BE MOUNTED AND SEALED ON A DRILL COLLAR

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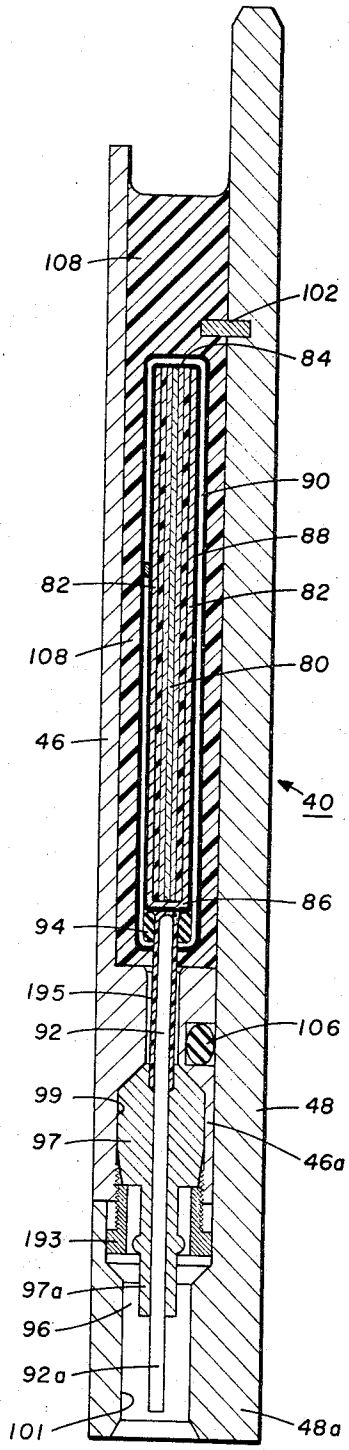


FIG. 6

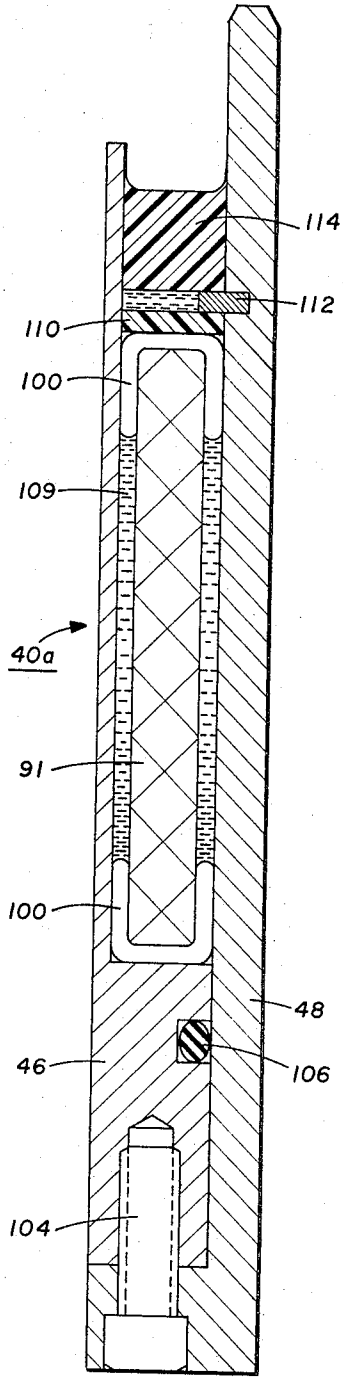


FIG. 7

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COIL ASSEMBLY STRUCTURE AND MOUNTING FORMING AN ANNULAR CHAMBER TO BE MOUNTED AND SEALED ON A DRILL COLLAR

Filed Dec. 23, 1964 4 Sheets-Sheet 4

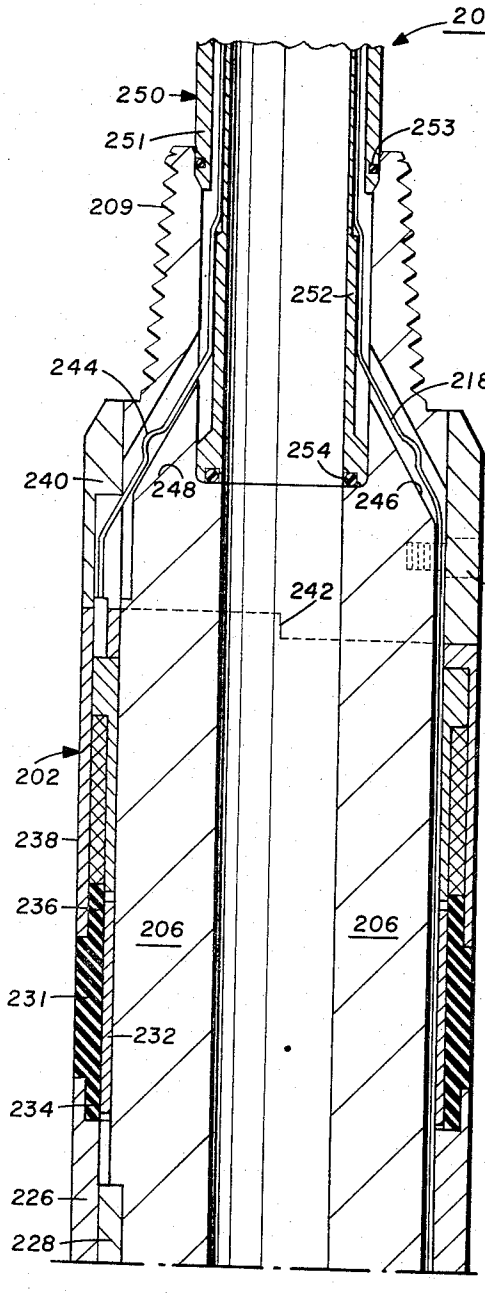


FIG. 8 A

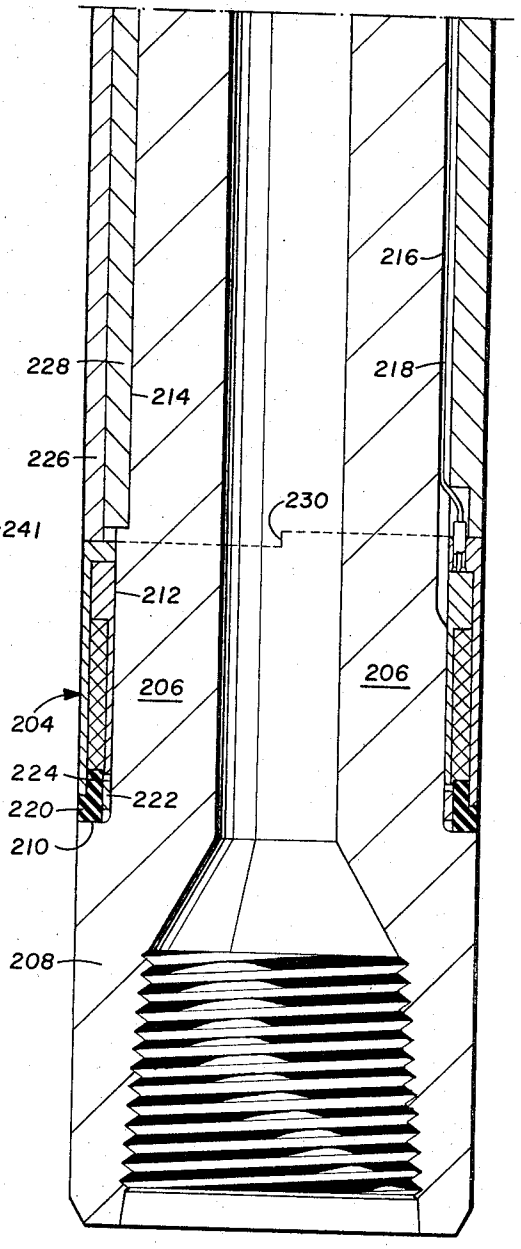


FIG. 8 B

United States Patent Office

3,377,549

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3,377,549

COIL ASSEMBLY STRUCTURE AND MOUNTING FORMING AN ANNULAR CHAMBER TO BE MOUNTED AND SEALED ON A DRILL COLLAR

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Filed Dec. 23, 1964, Ser. No. 420,544
9 Claims. (Cl. 324—6)

ABSTRACT OF THE DISCLOSURE

An apparatus for measuring formation resistivity while drilling having coil assemblies in the region of the drilling bit which is enclosed in fluid filled metallic chambers while avoiding a complete metallic electrically conductive path linked to the coil assemblies by employing open-ended annular chambers for the coil assemblies spaced apart with compression applied to resilient closures to retain the integrity of both assemblies while sealing the open-ended chambers.

This invention relates to well logging and has particular application to systems for determining properties or characteristics of earth formations in a borehole while the borehole is being drilled.

Various systems have been proposed or have been employed in the past for logging a well bore as it is being drilled to determine one or more characteristics of the formation being penetrated by the bit. In general, such methods of "logging while drilling" utilize a number of spaced electrodes placed near the lower end of, but insulated from the drill string. In some systems, the bit itself has been electrically insulated from the rest of the drill pipe so that electric current may be passed between the two electrically-insulated elements through the adjacent formation. The resistivity of the formation can then be determined by the flow of current from the drill string to the drill bit. These prior systems have inherent common disadvantages resulting primarily from the necessity to electrically insulate a section of the drill collar from the rest of the drill string. Available insulating materials cannot withstand the violent shocks in tension, compression and shear which must be transmitted mechanically through the drill stem to the bit.

In the type of system for logging resistivity while drilling disclosed in U.S. Patent No. 2,354,887, a toroid-shaped coil of wire wound on a core of ferromagnetic material encircles the drill collar near the drill bit with the axis of the toroid parallel to and preferably coinciding with the axis of the drill collar. The impedance of such a coil is affected by variations in the impedance of the electric path of its one-turn secondary winding consisting of the drill pipe, the formation near the drill bit and its return path through the earth to produce a measurement of the formation resistance adjacent the drill bit. It was found that the variations in the electrical resistance of the formation near the bit in the normal range of such values made it extremely difficult to make meaningful measurements. Therefore as described in copending U.S. application Ser. No. 298,298, entitled, "Formation Resistivity Measurement While Drilling," filed July 29, 1963, by Fletcher H. Redwine, et al., a system was described wherein both an input coil and a detector coil are used. The voltage induced in the detector coil as a result of the current induced in the one-turn secondary winding by the input coil is proportional to the conductivity of the formation near the drill bit.

Due to the extreme sensitivity required to measure the relatively small variations in the resistivity of the earth formations, considerable difficulty has been encountered in the physical construction of a sub carrying the two toroid coils which has the necessary sensitivity and also has a useful life of practical duration. The sensitivity problem is complicated by the fact that when the coils are lowered into the well bore they are subjected to a very high pressure. Experience has shown that often this pressure distorts the ferromagnetic coil to such an extent as to materially alter its magnetic properties and distort the measurements of the system. In fact, in some instances the magnetic properties of the system have been changed so radically that the measured values fall completely outside the calibration values previously obtained at the surface. The high pressures also tend to enter the sub and destroy the delicate electrical leads to the coils.

Another very real and difficult problem lies in the construction of a sub which is sufficiently rugged to withstand the high abrasion and shocks suffered by the sub and coils as the sub is rotated in the well bore, yet which does not interfere with the operation and sensitvity of the coils. The coils cannot be encased in an electrically-conductive material such as steel because the steel would in effect be a short-circuit to the system.

Therefore it is an important object of the present invention to provide a coil sub construction wherein the core material of the coil is protected from pressure differentials which would tend to distort the material.

Another object of the invention is to provide a coil sub of the type described wherein the delicate coils are protected by a case of steel without providing an electrically-conductive path around the coil.

A further object of the invention is to provide a coil sub of the type described which is relatively simple to manufacture and which may be assembled and overhauled with relative ease.

Another object of the invention is to provide a coil assembly which will not be adversely affected by changes in environmental pressures.

Still another object of the invention is to provide a coil sub which will better withstand the shocks, abrasion, pressures and temperatures of downhole drilling operations.

In accordance with the present invention, a rigid, annular, open-ended structure encircles a drill collar sub and forms an open-ended annular chamber. A toroidal coil is disposed in the chamber and around the sub, and the chamber is filled with a fluid material which will flow to equalize pressure as the sub is subjected to high bottom hold pressures. A rubber insulating ring is disposed around the sub adjacent the open end of the chamber and means are provided for forcing the end of the rubber ring against the structure. More specifically, the structure is formed of inner and outer sleeves which are interconnected at one end. The outer sleeve is longer at the open end than the inner sleeve, and the rubber insulating ring has an annular tongue which extends under the edge of the outer sleeve.

This invention also contemplates a sub assembly comprised of a tubular body having an annular shoulder formed at one end. Upper and lower coil assemblies are disposed around the body, each coil assembly being constructed as described above with the associated rubber insulating rings. A metal sleeve separates the coil assemblies and a means is connected to the tubular body to force the several parts together and against the shoulder as well as hold them in place on the tubular body.

Additional, more detailed aspects of the invention are hereafter pointed out in the appended claims, which, it is to be understood, constitute the sole limitations on the scope of this invention.

Additional objects and advantages of the invention will be apparent from the following detailed description and accompanying drawings, wherein:

FIGURES 1A and 1B, in conjunction, are a longitudinal sectional view of a coil sub constructed in accordance with the present invention;

FIGURE 2 is a perspective view of a toroidal coil constructed in accordance with the present invention;

FIGURE 3 is a perspective view of a portion of the coil assembly of FIGURE 2;

FIGURE 4 is a sectional view taken substantially on lines 4—4 of FIGURE 2;

FIGURE 5 is a sectional view taken substantially on lines 5—5 of FIGURE 4;

FIGURE 6 is an enlarged cross-sectional view of one side of a toroid coil assembly constructed in accordance with this invention which is used in the sub of FIGURES 1A–1B;

FIGURE 7 is a sectional view of an alternative toroid coil assembly constructed in accordance with the present invention which may be used in the sub of FIGURES 1A–1B; and,

FIGURES 8A and 8B, in conjunction, are a longitudinal sectional view of another coil sub constructed in accordance with the present invention.

Referring now to the drawings, and in particular to FIGURES 1A–1B, a coil sub constructed in accordance with the present invention is indicated generally by the reference numeral **10**. The upper half of the sub is shown in FIGURE 1A and the lower half is shown in FIGURE 1B. The sub **10** is comprised of a tubular body portion **12** having a central fluid passageway **14** extending therethrough, a standard thread box **16** at the lower end, and a standard thread pin **18** at the upper end. The pin of an adapter **20** is threaded into the box **16**, and the adapter **20** has a box **22** into which the conventional drill bit **23** may be threaded. The pin **18**, on the other hand, is connected to a special sub (illustrated in dotted outline and designated by the reference numeral **21**) which contains a telemetering system for transmitting the resistance values measures by the sub **10** to the surface as a series of pressure pulses in the mud stream as described in greater detail in the above-referenced patent application. The body portion **12** has a maximum diameter at **24** and is turned down to a diameter **26** below the shoulder **28** formed by the lower end of a band **30** welded to the body by a seam **32**. The band **30** covers bores **34** and **36** which form passageways for conductors which will presently be described. Elongated grooves **38** (only one of which is illustrated) extend downwardly along the turned-down portion **26** of the body **12** to form passageways for electrical lead wires extending from the lower end of the sub **10** as will presently be described.

An upper coil assembly, indicated generally by the reference numeral **40**, is disposed around the turned-down portion **26** and abuts against the band **30**. The upper end of the coil assembly **40** is keyed to the band **30** and therefore to the body **12** by means of longitudinally-extending shoulders, one of which is indicated in dotted outline at **42**. It is necessary to key the coil assembly **40** to the body **12** so that the coil assembly **40** will not rotate and shear the electrical leads to the coil which will hereafter be described. The coil assembly **40** has a toroidally-wound coil **44** which is received within an open-ended chamber formed by an inner sleeve **46** and an outer sleeve **48**. The construction of the toroidal coil **44** will hereafter be described in considerably greater detail. The sleeves **46** and **48** are fabricated from metal and the upper ends of the sleeves are joined together by annular overlapping shoulder portions **46***a* and **48***a* where they are bolted together. The lower end of the outer sleeve **48** is substantially longer than the lower end of the inner sleeve **46**, and the lower ends of the two sleeves are separated so as to interrupt the conductive path around the coil. A continuous metal path, in essence, would constitute a short circuit to the system. An electrically non-conductive ring **50**, preferably fabricated from rubber, is adherently bonded to a metal or other rigid sleeve **52** for support and is disposed around the body **12**. The ring **50** has an upper lip **54** which extends under the lower end of the ring **48** and a lower lip **56** which extends under a metal sleeve **58** which is also disposed around the body portion **12**. The sleeve **58** is secured against rotation relative to the body **12** by a key **60** which is fitted in longitudinally-extending grooves in the sleeve and body.

A lower coil assembly indicated generally by the reference numeral **62** of substantially the same construction as the upper coil assembly **40** is abutted against the lower end of the sleeve **58** and is keyed to the sleeve **58** to prevent rotation about the body **12** by key shoulders, one of which is indicated in dotted outline at **64**. The lower coil assembly **62** is substantially identical to the upper coil assembly **40** and is also comprised of an inner sleeve **65**, an outer sleeve **66**, and a toroidal coil **68**. A snap ring **70** fits in a groove at the lower end of the body **12** to retain the coil assembly **62**, sleeve **58**, insulating ring **50** and upper coil assembly **40** on the body **12** merely to facilitate assembly. A lower insulating ring **72**, preferably fabricated of rubber, is bonded to a metal backup ring **74** and has a lip portion **76** which extends under the lower end of the outer sleeve **66**. The adapter **20** has a shoulder **78** which abuts against the lower end of the body **12** and the insulating ring **72**. The total length of the sleeve-like members which are positioned around the body **12** exceeds the distance from the shoulder **28** to the lower end of the body **12** so that the insulating rings **72** and **50** will be pressed against the open ends of the coil assemblies **40** and **62**, and in particular against the lower ends of the outer sleeves **48** and **66**, and the several sleeve members held in place on the body.

The coil assembly **40**, for example, is shown in FIGURE 2. The coil assembly is comprised of a number of turns **90** of a thin magnetic core material. The core material is commercially available and may be several inches in width and have a thickness like that of a thick metal foil or thin sheet metal. The core material **80**, referring to FIGURE 5, is housed within a U-shaped aluminum box **82** having a closed end **86** and an open end **84**. The box is then preferably wrapped in a suitable tape **88**, such as Mylar tape or the like, in order to facilitate assembly. A circular plastic retainer ring **94** (see FIGURE 3) having a U-shaped cross section (see FIGURES 4 and 5) containing semicircular, stiff lead wires **92** and **93** is then positioned against the closed end of the box **82** and taped in place by tape **89**. The lead wires **92** and **93** are enclosed in insulating sleeves and have portions **92***a* and **93***a* which extend through apertures in the retaining ring **94** and extend parallel to the axis of the coil to provide the male halves of bayonet-type couplings to be described. The other ends of the lead wires **92** and **93** have flexible pigtail portions **92***b* and **93***b* which also extend through openings in the plastic ring **94**. Next a number of U-shaped plastic feet or spacers **100** are placed at peripherally spaced points over the opposite ends of the box **82** and glued in place. Then the wire windings **90** of the toroidal coil assembly are connected to one of the pigtail portions **92***b* or **93***b* of one lead wire and wrapped around the core box **82** with uniformly spaced turns, then connected to the pigtail portion of the other lead wire. The entire assembly may then be further wrapped with Mylar tape **95** wound by toroidally and circumferentially to protect the windings **90**.

Next the coil assembly is slipped down over the inner sleeve **46** as illustrated in FIGURE 6. The spacers **100** make a snug fit with the sleeve **46**. The leads **92** and **93** are passed through bores **95** (only one being illustrated in FIGURE 6), and through a plastic sealing grommet **97** positioned in a counterbore **99**. An insert **93** is threaded into the counterbore **99** to swage the sealing grommet around the lead wire **92**. The end **92***a* of the lead wire **92**

together with the shank **97***a* form the male portion **96** of a bayonet coupling. The outer sleeve **48** is then placed around the inner sleeve **46** with the shoulder **48***a* abutting the shoulder **46***a* and bores **101** positioned to receive the male halves **96** of the couplings. The inner and outer sleeves **46** and **48** may be interconnected by socket head screws (such as the screw **104** in FIGURE 1A) which extend through the inwardly-directed shoulder portion **48***a* of the outer sleeve into the outwardly-directed shoulder portion **46***a* of the inner sleeve. An O-ring **106** may be provided between the shoulder portion **46***a* of the inner sleeve and the outer sleeve **48** to effect a fluid seal. A retaining ring **102** is snapped in place to retain the core within the annular cavity formed between the inner and outer sleeves **46** and **48**.

The annular chamber formed between the inner and outer sleeves **46** and **48** is filled with a suitable potting fluid material **108**. The potting fluid **108** is preferably a silicon potting compound such as General Electric's silicon compound RTV No. 615. The silicon potting compound is highly fluid when first placed in the cavity so that it permeates the various layers of Mylar tape wound about the core box **82** and uniformly distributes itself between the turns of magnetic core material **80**. When the potting compound **108** is cured, it has a consistency similar to stiff gelatin and the assembly **40** can be inverted to the position shown in FIGURES 1A and 1B for assembly without any flow of the potting material. However, when the exposed surface of the potting material is subjected to bottom hole pressure, the material is sufficiently fluid to exert a uniform and equalized pressure on all exposed surfaces so as to insure that the delicate core material and wire windings are not stressed and deformed to vary their electric or magnetic properties.

An alternative construction for the core assembly **40** is illustrated in FIGURE 7 and is designated generally by the reference character **40***a*. The coil assembly **40***a* is substantially identical with the coil assembly **40** except that oil **109**, such as hydraulic fluid, is used for the potting compound which fills the chamber formed between the inner and outer sleeves **46** and **48**. Accordingly the core **80** and windings **90** are represented collectively and schematically by the reference character **91**. In the assembly **40***a*, a crush ring **110** is provided at the open end of the annular chamber adjacent the spacers **100**. The crush ring **110** is retained in place by a snap ring **112** which may be located in the inner wall of the outer sleeve **48**. The oil is sealed in the chamber by an annular elastic seal **114** which is press-fitted between the ends of the inner and outer sleeves **46** and **48**. The sealing ring **114** and the O-ring seal **106** are adequate to retain the oil within the chamber. Downhole pressure acting on the sealing ring **114** will be transmitted to the oil within the chamber to equalize the pressure around the core and prevent distortion and stress.

The electrical leads **120** to the upper coil assembly **40** are connected by a female coupling **98** to the male coupling **96** and extend upwardly to a second male coupling **122** through the passageway formed by a cavity **124** in the ring **30**, the bore **36**, and a bore into which the male half of a coupling half **122** is threaded. The lead wires **126** from the lower coil assembly **62** are connected to the wires of the coil **68** by a bayonet-type coupling **128** and extend upwardly through a passageway formed by a cavity **130** in the body **12**, a cavity **131** formed in the sleeve **58**, the groove **38** cut in the body **12**, the bore **34**, and a bore into which the male half **132** of a second bayonet coupling is threaded. Although only one lead wire for each of the coils **40** and **62** is illustrated, it will be understood that two such lead wires are provided at peripherally spaced points around the body **12**.

The electrical lead wires **120** and **126** are connected to a telemetering system as heretofore described by means of a cross-over assembly indicated generally by the reference numeral **133** and illustrated in FIGURE 1A. The

cross-over assembly **133** is comprised of a body **134** which has an annular flange **135** which abuts a resilient gasket **136** against the end of the pin **18** of the body **12** to absorb vibration. A body **134** has a first sleeve portion **138** which extends into a counterbore **140** in the pin **18** and abuts against the shoulder **142** formed between the counterbore **140** and bore **14**. An O-ring seal **144** is provided to seal the upper end of cavities **146** and **148** which receive the male coupling halves **122** and **132**. A second sleeve portion **150** extends downwardly into the bore **14** and the space between the sleeve portion **150** and body **12** is sealed by a pair of O-ring seals **152** to seal the lower ends of the cavities **146** and **148**. Female coupling halves **154** and **156** for mating with the male halves **122** and **132** are threaded into bores in the body **134** and are connected to electrical lead wires **158** and **160** which extend upwardly through passageways to a master coupling **162** which contains axially-spaced contacts for all four electrical leads. A plurality of elongated slots **164** permit fluid to pass back into the passageway **14** after having passed through the fluid annulus formed in the telemetering sub **21**. The sub **21** has an annular shoulder **165** which abuts against the shoulder **135** to secure the cross-over assembly **133** in position between the two subs.

When assembling the tool **10**, the coil assemblies **40** and **62** are assembled and potted in the fluid material as previously described. The leads **120** and **126** are placed in the respective passageways and the couplings **122** and **132** threaded into the respective bores. The coil assembly **40** is slipped over the lower end of the body **12** and the couplings **96** and **98** connected. The key shoulders **42** are then mated and the excess length of the lead **120** folded in the cavity formed by the bore **36**. Next the insulating ring **50** is slipped over the end of the body **12** into place. The key **60** is positioned in the mating groove in the body **12** and the metal sleeve **58** slipped into position. Then the lower coil assembly **62** is slipped over the body **12** and the electrical leads interconnected by the couplings **128**. The excess length of the lead **126** may then be crimped into the cavities **34** or **130–131** as the coil assembly is abutted against the lower end of the sleeves **58** and the keying shoulders **64** engaged. The snap ring **70** is then inserted to hold these members in place on the body **12**. Next the lower insulating ring **72** is positioned around the body **12** and the adapter **20** threaded tightly into the box **16**. A suitable potting material is pumped under relatively high pressure into all cavities formed between the various members. For example, the potting material may be pumped inwardly through the bores **170** to fill the cavities formed by the bores **34** and **36**. A number of additional bores (not illustrated) may be provided at spaced points around the periphery and over the length of the tool for the injection of the potting fluid. It is particularly important that the potting fluid completely fill all cavities associated with the electrical leads. Otherwise, the bottom hole pressures will force the potting materials, along with the lead wires, into any unfilled cavities and thereby sever the electrical leads.

Next the cross-over assembly **133** is inserted in the pin **18** and the couplings **154** and **156** aligned and mated with the couplings **122** and **132**. It will be noted that the cavities containing these couplings are not filled with a potting material but are completely sealed by the O-rings **144** and **152** and the threaded connections between the coupling halves and the sub body **12** and cross-over **134**. The telemetering equipment is connected through the coupling **162** and the sub **21** threaded onto the pin **18** so as to bear on the annular shoulder **135** and securely retain the cross-over assembly **133** in place between the two subs.

When the sub **10** is lowered into the well bore, the high downhole pressure will enter through the various abutting joints and apertures and place the potting material under uniform compression. If all the apertures

and voids within the assembly are properly filled with the potting material, the potting material will not migrate and the various electrical leads and various other delicate members of the assembly will not be harmed.

In accordance with an important aspect of this invention, the downhole pressure acting on the cavity formed between the inner and outer rings **46** and **48** will be transmitted uniformly throughout the fluid potting material **108** or **109**, as the case may be, which has permeated the box **82** containing the magnetic core material **80**. This is important because if the magnetic core material **80** is bent, stretched, or significantly deformed, its magnetic characteristics are changed such that previous calibrations of the core assembly become inaccurate and often are changed to such an extent as to exceed the range of the recording instruments. The toroidal coils are protected by the steel sleeve **48** such that the normal abuse suffered by the sub in the drilling operation does not adversely affect the delicate coils. The rubber insulating rings **50** and **72** are partially protected by the adjacent steel sleeve **48** and sleeve **58** and the adapter **20** and therefore have a relatively long life.

Another coil sub constructed in accordance with the present invention is indicated generally by the reference numeral **200**. The upper half of the sub is illustrated in FIGURE 8A and the lower half is illustrated in FIGURE 8B. The sub **200** employs upper and lower toroidal coil assemblies **202** and **204** both of which are of the same construction as the coil assemblies **40** or **62** heretofore described. However, the sub **200** has a body **206** having a maximum diameter portion **208** which forms a box for receiving the pin of a conventional drill bit. A pin **209** is formed at the other end of the body. The body **206** has an upwardly-facing shoulder **210** formed between the maximum diameter of the portion **208** and a minimum diameter portion **212**. The minimum diameter portion **212** is of uniform diameter except for a keyway **214** and a pair of grooves **216** (only one of which is illustrated) for the electrical lead wire **218** to the lower coil assembly **204**. A lower insulating ring **220** is bonded around a metal reinforcing band **222** and the lower end is abutted against the shoulder **210**. The outer sleeve of the lower coil assembly **204** extends down over the lip portion **224** of the insulating ring **220**. A sleeve **226** is splined to the body **206** by a key **208** received in the groove **214**. The upper end of the coil assembly **204** is keyed to the sleeve **226** by mating offset semicircular extensions which abut along opposite shoulders **230** shown in dotted outline. An upper insulating ring **231** is bonded to a metal band **232** and has a tongue portion **234** on the lower end which extends under an annular lip formed at the upper end of the sleeve **226**, and a tongue portion **236** which extends under the lower end of the outer band **238** of the upper coil assembly **202**. The lower end of a retaining sleeve **240** abuts against the upper end of the coil assembly **202** and the two parts are keyed against relative rotation by opposite vertical shoulders **242** indicated in dotted outline. The retaining sleeve **240** is secured on the body **206** and is also secured against rotation relative to the body **206** by a plurality of set screws **241** spaced about its periphery which are threaded into recesses formed in the body **206**.

Thus it will be noted that the lower coil assembly **204** is secured against rotation by the keyed connection to the metal sleeve **226** which is in turn splined to the body **206**, and the upper coil assembly **202** is secured against rotation by the keyed connection to the retaining sleeve **240** which is in turn secured to the body **206** by the set screws **241**. Of course the set screws **241** also secure the insulating ring **220**, coil assembly **204**, sleeve **226**, insulating ring **231**, and coil assembly **202** in place on the body **206** in close, abutting, end-to-end relationship. The electrical lead wire **218** to the lower coil assembly **204** and the lead wire **244** to the upper coil assembly **202** may extend through passageways formed by bores **246** and **248**, respectively, to a cross-over assembly **250**.

The cross-over assembly **250** has a tubular body **251** which is inserted in a counterbore **252** in the pin **209**. O-ring seals **253** and **254** seal the pressure within the drill string from the pressure outside the drill string and also isolate the passageway for the lead wires. The upper portion of the cross-over assembly **250** may be constructed similar to that of the cross-over assembly **133** and accordingly is not illustrated.

The principal difference between the sub **200** and the sub **10** is the manner in which the various sleeve components are assembled and held in place on the respective bodies **12** and **206**. In the sub **10**, the adapter **20** is used to secure the various slipon components in place, and the components are slipped on from the lower end of the body **12**. In the sub **200**, both the box **208** and the pin **209** are integral with the sub, and the components are slipped on from the top and screwed in place by the retaining sleeve **240** and the set screws **241**. The sub **200** is preferably potted as described in connection with the sub **10** so that all voids in the structure are uniformly filled with a fluid potting material. However, the cross-over assembly **250** must first be placed in the position illustrated before the potting material is introduced under pressure so that the passageways for the electrical lead wires **218** and **244** will be filled.

From the above detailed description of preferred embodiments of the invention, it will be noted that an improved coil sub has been described wherein the coils are well protected from abrasion and impact by the steel rings forming the open-ended annular chambers in which the coils are disposed. Further, the construction is such that the pressure around the individual turns of the magnetic core material is equalized at all times to prevent distortion. Thus as the tool is subjected to the great bottom hole pressures, the delicate core material is not warped, bent, or stretched and continues to have the same magnetic properties. All voids in the coil sub are filled with fluid potting material so as to prevent damage to the delicate electrical leads. The strong metallic housing for the toroidal coils does not, however, form a complete electrical path around the coil which would constitute a shorted turn and prohibit making the measurements which are required.

Although preferred embodiments of the invention have been described in detail, it is to be understood that various changes, substitutions, and alterations can be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. In a system for logging formation resistivity while drilling in a borehole, a coil subcombination comprising:

a tubular body adapted to be connected into a drill string having a central bore extending therethrough and an annular shoulder formed adjacent one end,

upper and lower coil assemblies disposed around the tubular body, each coil assembly being comprised of a rigid, annular, open-ended housing forming an open-ended chamber, a toroidal coil disposed in the open-ended chamber, and a fluid material filling the voids in the annular chamber,

a rubber insulating ring disposed around the tubular body adjacent the open end of each coil assembly and engaging the responsive assemblies,

a metal sleeve disposed around the tubular body and separating the coil assemblies, and

means connected to the end of the tubular body opposite from said shoulder for forcing the coil assemblies, the rubber insulating rings, and the metal sleeve into end-to-end abutting relationship between said means and said shoulder and for retaining the assemblies, rings and sleeves in place on the tubular body.

2. The coil sub defined in claim **1** wherein said means comprises:

an adapter structure threadedly connected at one end to said tubular body and abutting the rubber insulating ring adjacent the open end of said lower coil assembly.

3. The coil sub defined in claim 2 wherein:

one end of the upper coil assembly is disposed adjacent the annular shoulder and is keyed therewith to prevent rotation,

one rubber insulating ring is disposed adjacent to the other end of the upper coil assembly,

one end of the metal sleeve is disposed adjacent said one rubber insulating ring and is keyed to the tubular body to prevent rotation,

one end of the lower coil assembly is disposed adjacent the other end of the metal sleeve and is keyed therewith to prevent rotation,

the other rubber insulating ring is disposed adjacent the other end of the lower coil, and

the adapter structure abuts against said other rubber insulating ring.

4. The coil sub defined in claim 1 wherein:

the annular shoulder is disposed in the region below said lower coil assembly, and

the means connected to the end of the tubular body is a second sleeve disposed around the tubular body and secured thereto by set screws.

5. The coil sub defined in claim 4 wherein:

one end of one of the rubber insulating rings is disposed adjacent to the annular shoulder,

the open end of one of the coil assemblies is disposed adjacent the other end of said one rubber insulating ring,

one end of the metal sleeve is disposed adjacent the other end of said one coil assembly and is keyed to the coil assembly and to the tubular body to prevent rotation,

one end of the other rubber insulating ring is disposed adjacent to the other end of the metal sleeve,

the open end of the other coil assembly is disposed adjacent the other end of the other rubber insulating ring, and

the other end of the other coil assembly is disposed adjacent the second sleeve and is keyed therewith to prevent rotation of the coil assembly.

6. The coil sub defined in claim 1 further characterized by:

passageways for electrical lead wires extending through the sub from each of the coil assemblies to one end of the sub,

electrical lead wires extending through the passageways and connected to the respective coils and to electrical couplings at said one end of the sub, and

a fluid potting material filling the passageways and all voids in fluid communication therewith to prevent migration of the lead wire as a result of unequalized down hole pressures.

7. The coil sub defined in claim 6 further characterized by:

a counterbore in one end of the tubular body forming an outwardly-facing annular shoulder, the electrical lead wires being connected to bayonet coupling halves disposed at peripherally spaced points around the annular shoulder and aligned parallel to the axis of the sub,

a cross-over assembly including a tubular portion inserted in the counterbore and having mating coupling halves in the end of the whole portions connected to said bayonet coupling halves around the annular shoulder, lead wires connected to said mating coupling halves extending through passageways to the other end for connection to additional circuitry, fluid ports in the sides of the cross-over assembly for passing drilling fluid from the outside to the inside of the tubular portions, and

annular sealing means between the cross-over assembly and the tubular body on each side of the mating couplings for forming a fluid-tight chamber around the couplings.

8. The coil sub defined in claim 7 wherein:

the coupling halves are threadedly connected to the respective tubular body and cross-over assembly to provide a fluid-tight seal.

9. The coil sub defined in claim 6 further characterized by

a counterbore in one end of the tubular body forming an outwardly-facing annular shoulder,

a cross-over assembly housing a tubular portion disposed in the counterbore,

passageways in the cross-over assembly forming continuations of the passageways in the tubular body of the sub and extending to the outer end of the cross-over assembly,

annular sealing means between the tubular portion and the tubular body disposed on opposite sides of the passageways to seal the passageways from fluid within and without the sub, and wherein

the electrical leads extend through the passageways in the cross-over assembly to coupling halves at the upper end of the cross-over assembly.

References Cited

UNITED STATES PATENTS

2,411,696	11/1946	Silverman et al.	324—1 X
2,964,698	12/1960	Lehmberg	324—10
3,079,549	2/1963	Martin	324—6 X
3,249,857	5/1966	Simon-Suisse	324—6

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