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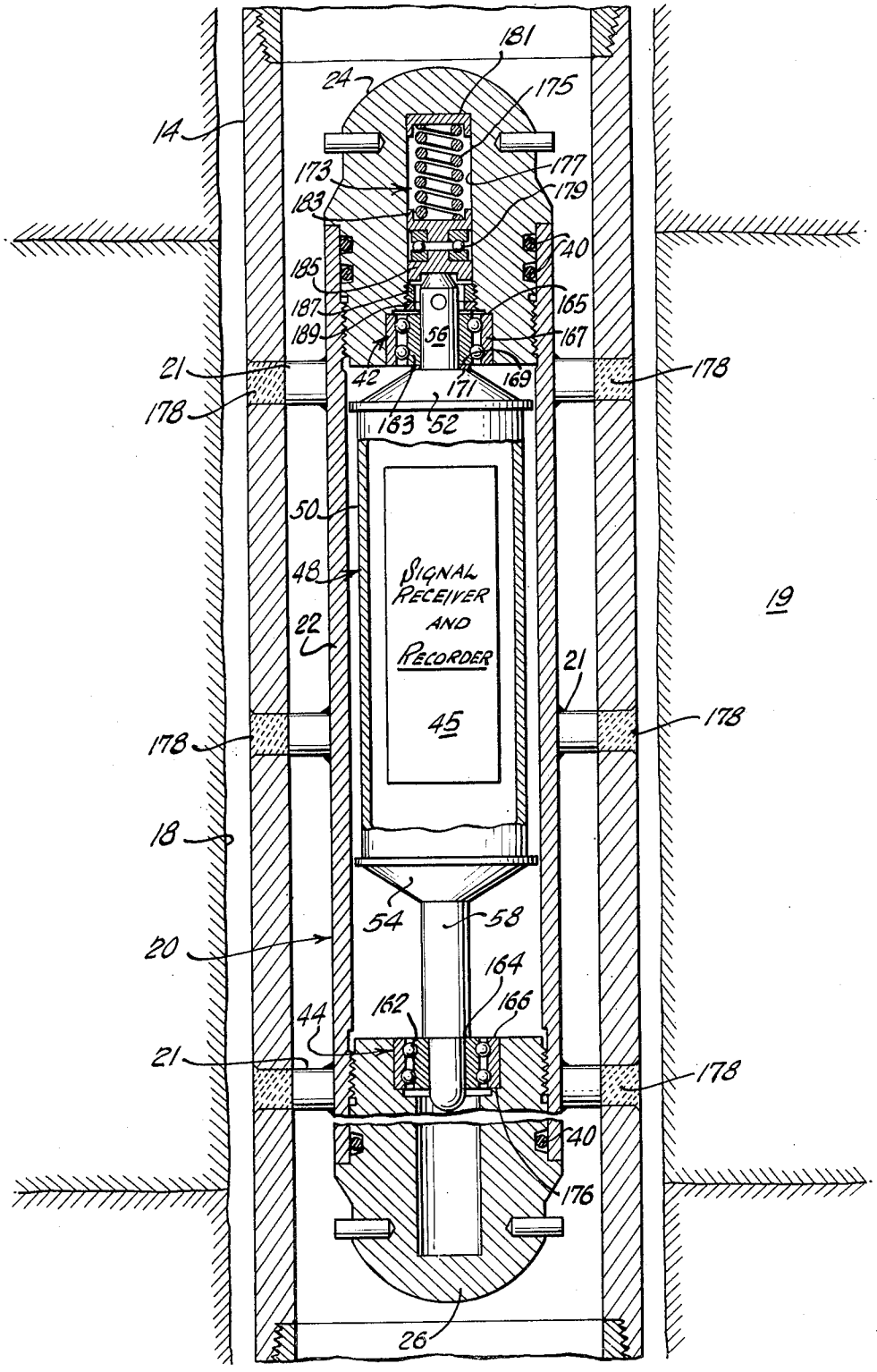

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WELL LOGGING APPARATUS

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This invention relates to apparatus for use in well surveying, and more particularly, to apparatus for well surveying which may be utilized simultaneously with the drilling process of a borehole.

In the conventional method of logging a borehole, the log is obtained while the drill operation is periodically interrupted, during which period the drill pipe is removed and a logging instrument suspended by a steel-shrouded multiconductor cable is lowered into the borehole. As the instrument penetrates different geological strata information in the form of electrical signals is transmitted from the bottom of the borehole to the surface through the conductor cable where it is recorded on a chart.

In order to eliminate the disadvantages encountered during the interruption in the drilling process of a borehole, a method of geophysical prospecting has been developed which comprises drilling a borehole, simultaneously and continuously detecting a physical variable in the borehole, simultaneously and continuously recording in the hole the physical variable and simultaneously and continuously recording indications of the depth at which the physical variable is being detected.

In accordance with this invention, apparatus has been developed for use in a logging while drilling operation which comprises a tubular member or housing adapted to be inserted in a drill stem or string, preferably in the vicinity of the drill bit, a sealed container or pressure-tight capsule disposed in and rigidly secured to the housing and adapted and arranged to permit the passage of fluid through the housing, an instrument casing disposed within said pressure-tight capsule and mounted axially so as to be freely rotatable about the longitudinal axis of the housing, the mounting means of said casing including resilient means disposed between the instrument casing and the pressure-tight capsule for eliminating or minimizing movement of the casing along the longitudinal axis thereof with respect to the capsule.

In order that the invention may be more clearly understood and readily carried into effect it will now be described more fully with reference to the accompanying drawing in which the figure illustrates the apparatus of the invention.

In the figure there is shown a tubular housing or pipe **14** which is preferably disposed in the lower portion of a drill stem or string of a borehole or well drilling apparatus, preferably between the drill bit and drill collar thereof, which is used to drill a borehole **18** traversing one or more formations of the earth, for example, **19**. A sealed container or capsule **20** adapted to withstand pressures of at least 14,000 pounds per square inch is disposed coaxially within the housing **14** and is rigidly secured thereto by support pins or studs **21**, which are preferably made of stress-proof steel. The capsule **20** includes a hollow cylinder **22** which is preferably made of stainless steel, and top and bottom caps **24** and **26** respectively. The top and bottom caps **24** and **26** of the capsule **20** threadedly engage the cylinder **22**, cap **24** preferably having a left hand thread and cap **26** preferably having a right hand thread. O-rings **40** are located between the caps **24**, **26** and the cylinder **22** to provide effective pressure seals for the capsule **20**. Disposed in the top and bottom caps **24** and **26** along the axis of the cylinder **22** are thrust bearings **42** and **44** respectively. Disposed within the pressure-tight capsule **20** is an inner

case **48** for housing logging equipment, for example, a signal receiver and recorder **45**, which comprises a hollow cylinder **50** and upper and lower end plates **52** and **54** having support shafts **56** and **58**, respectively, which are preferably made of SAE No. 3140 heat treated alloy steel having a yield point of 130,000 p.s.i. The shafts **56** and **58** are disposed along the axis of the inner case **48** and are adapted to be received by the thrust bearings **42** and **44**, respectively, in the caps **24** and **26** to provide an arrangement for substantially isolating the inner case **48** from torsional forces in the housing **14** and in the pressure-tight capsule **20**, which forces may be applied to the drill string at the earth's surface in a rotary drilling process or in the borehole in a turbo drilling process.

The lower bearing **44** is essentially a ball bearing having an inner race **162** upon which a shoulder **164** of the bottom support shaft **58** is seated and an outer race **166** which is seated upon a shoulder **176** of the bottom cap **26**. The top support shaft **56** of the inner case **48** is similarly held in the top cap **24** of the capsule **20** by the top thrust bearing **42**. The top thrust bearing **42** is also essentially a ball bearing having an inner race **163** and an outer race **167**, a shoulder **165** of the upper cap **26** being seated on the outer race **167** and the inner race **163** being seated on a washer **169**, preferably a steel washer, which is in turn seated on a shoulder **171** of the top shaft **56**. The thickness of the washer **169** may be selected so as to provide necessary clearance for expansion of the inner case **48** depending upon the anticipated range of temperatures in a borehole. Whenever high temperatures are anticipated in the borehole, a thin washer may be used or the washer may be entirely eliminated, so as to provide room for expansion of the apparatus without binding the freely rotatable inner case **48** between the top and bottom caps **24** and **26**. The washer can also be used to serve as an adjustment for slight differences in the lengths of various inner cases which may be used in the pressure-tight capsule **20**.

When the thickness of the washer **169** is such that clearance for expansion of the inner case **48** is provided in the pressure-tight capsule **20**, the inner case **48** will tend to vibrate in the capsule **20** during the drilling process whenever temperatures below the maximum temperatures are encountered, thus producing forces in the inner case **48** in the direction of the longitudinal axis thereof which could adversely affect the logging equipment housed in the inner case **48**. In order to eliminate or minimize the longitudinal vibrations, resilient means **173** are disposed between the inner case **48** and the pressure-tight capsule **20** so as to oppose longitudinal forces which may tend to set up vibrations in the inner case **48**. The resilient means **173** preferably includes a compression spring **175**, for example, a 200 lb. compression spring, disposed in a chamber **177** in the top cap **24** of the pressure-tight capsule **20** along the longitudinal axis of the inner case **48** between the end of the top support shaft **56** and end wall of the chamber **177**. The compression spring **175** is held in position in the chamber **177** by engaging at its upper end a spring retainer **181** and at its lower end a spring thrust plate **183**. A second top thrust bearing **179** is disposed in the chamber **177** of the top cap **24** along the longitudinal axis of the inner case **48** between the end of the top support shaft **56** and the compression spring **175** to eliminate or minimize the frictional forces between the spring **175** and the top support shaft **56**. The second top thrust bearing **179** is held in position in the chamber **177** between the spring thrust plate **183** and a top shaft thrust plate **185** which engages the end of the top shaft **56**. In order to prevent the compression spring **175** and the second thrust bearing **179** from sliding out of the chamber **177** in the top cap **24** when the top cap **24** is removed from the cylinder **22**, a locking ring

187 and a jam nut 189 are secured to the top cap 24 by threadedly engaging the top cap 24 at the mouth of the chamber 177.

Accordingly, it can be seen that by utilizing a spring which has a suitable compressional force exerted on the upper end of the upper shaft 56 the inner case 48 will be prevented from jarring against its supporting apparatus.

In order to rigidly connect the capsule 20 to the housing 14 a number of the support pins or studs 21, for example, twelve pins, are welded at suitable points to the outside surface of the capsule 20 and a like number of holes or openings 178 are drilled through the housing 14 at points which are spaced so as to be aligned with the welded pins 21 when the capsule 20 with the welded pins 21 is inserted into the housing 14. After the pins 21 are aligned with the openings 178 each pin is welded to the housing 14 through its corresponding opening and each of the openings 178 is filled with the weld so as to provide a housing with a smooth exterior surface.

The inner case 48 and the pressure-tight capsule 20 have been constructed so that the inner case 48 can be easily inserted into and removed from the pressure-tight capsule 20. When the inner case 48 is placed in the capsule 20, the bottom shaft 58 is received in the bottom thrust bearing 44 with the shoulder 164 of the bottom shaft 58 engaging the bearing 44. The top cap 24 with the top thrust bearing 42, which receives the top shaft 56, and the resilient means 173 is placed over the top shaft 56 and secured to the cylinder 22 of the capsule 20. The top and bottom bearings 42 and 44 and the top and bottom shafts 56 and 58 are disposed on the longitudinal axis of the tubular pipe 14. Accordingly, it can be seen that the arrangement of this apparatus supports the inner case 48 in a manner which will protect sensitive logging equipment from angular shock or excessive angular acceleration or deceleration.

It should be understood that the apparatus of this invention may be inserted in a rotary drill string or in a turbo drill string. When the apparatus of this invention is used in a rotary drill string, it is preferably inserted between the drill bit and the lowermost drill collar. When the apparatus is used in a turbo drill string it may be inserted between the drill pipe and the turbine, or if it is desired to place the logging equipment closer to the drill bit the apparatus may be inserted in the turbo shaft between the turbine and the drill bit.

When the drill string including the well surveying apparatus is completely assembled the drill bit may be rotated by a suitable prime mover in the usual manner since the housing 14 has been designed to withstand forces which are equal to or greater than the rated strength of other sections of the drill string. Furthermore, the mud flow through the drill string is not substantially retarded by the apparatus since the cross-sectional area of the mud duct between the inner surface of the tubular housing 14 and the external surface of the capsule 20 is equal to or greater than the cross-sectional area of the opening through a conventional drill collar.

Since the drill string is withdrawn from the drill hole approximately once every 24 hours in rotary drilling operations, and more frequently in turbo drilling operations, in order to inspect or remove the drill bit, the record or log produced by the logging equipment disposed in the inner case 48 can be viewed at least once every 24 hours with a minimum of disturbance in the drilling operation. Each time that the bit is taken out of the hole the drill stem is broken at the joint at the upper end of the housing 14, i.e., at the joint nearest to the top cap 24 of the capsule 20. The top cap 24 is then removed from the capsule 20 and the inner case 48 is withdrawn from capsule 20. The top end plate 52 may then be removed from the cylinder 50 of the inner case 48 and the logging equipment withdrawn from the inner case 48.

It should be understood that logging equipment, such as that which provides radioactivity, vibration, or temperature logs, may be disposed wholly within the inner case 48. However, this apparatus may also be utilized when a sensing element is required outside of the inner case 48, capsule 20 or the housing 14, for example, as when pressure, r.p.m. of drill bit, self potential or resistivity logs are desired. It should also be understood that in order to obtain resistivity logs of the borehole simultaneously with the well drilling operation electrodes suitably connected to the recorder must be disposed at the outer surface of the housing 14 and suitably insulated therefrom. Furthermore, the short circuit effect of a metallic housing must be taken into consideration when resistivity logs are being produced. Such resistivity logging while drilling systems are described more fully in the copending application of Clements, Lee and Stelzer having Serial No. 677,969, filed August 13, 1957, and entitled Geophysical Prospecting Apparatus.

Accordingly, it can be seen that this invention provides rugged logging apparatus which may be readily located in the drill string near the drill bit to log the subsurface formations or the borehole simultaneously with the drilling process. Although the apparatus of this invention is utilized under severe requirements of heat and mechanical vibration and shock at the point of drilling, the apparatus is so constructed that even D'Arsonval-type galvanometers may be successfully employed in the recording circuit of the logging equipment.

Obviously, many modifications and variations of the invention as hereinabove set forth may be made without departing from the spirit and scope thereof and therefore only such limitations should be employed as are indicated in the appended claims.

We claim:

1. Apparatus comprising a tubular member adapted to be coupled in a drill string in the vicinity of the rotatable drill bit, a pressure-tight capsule disposed within and rigidity secured to said tubular member, an inner case including apparatus for conducting a log in the borehole disposed within said capsule and means for mounting said inner case within said capsule for substantially free rotation therein about the longitudinal axis thereof, said longitudinal axis of said inner case being disposed substantially along the longitudinal axis of said drill string, said mounting means including resilient means comprising a spring mounted in compressional relationship between said capsule and said inner case and being oriented to apply pressure between said capsule and said inner case along said longitudinal axis, thereby comprising means for opposing upward movement of said inner case along the longitudinal axis thereof with respect to said pressure-tight capsule, thereby substantially to eliminate longitudinal chatter while maintaining said housing freely rotatable.

2. Apparatus for well logging comprising a tubular member adapted to be coupled in a drill string in the vicinity of the drill bit, a pressure-tight capsule disposed within and rigidly secured to said tubular member so as to provide a fluid passage through said tubular member, an inner case including apparatus for conducting a log in the borehole disposed within said capsule and means for supporting said inner case within said capsule so as to permit said inner case to be freely rotatable therein about the longitudinal axis of said tubular member, said supporting means including a compression spring mounted in compressional relationship between the upper end of said capsule and said inner case and characterized in that the opposing force thereof is directed along said longitudinal axis in a given direction, thereby to oppose movement of said inner case along said longitudinal axis with respect to said pressure-tight capsule.

3. Apparatus as defined in claim 2 further comprising bearing means disposed between said spring and said inner case for preventing rotational forces from being transferred between said spring and said inner case.

4. Apparatus comprising a tubular member adapted to be coupled in a drill string in the vicinity of the drill bit, a pressure-tight capsule disposed within and rigidly secured to said tubular member in spaced relation thereto so as to provide a fluid passage through said tubular member, said capsule having first and second caps at opposite ends thereof respectively, an inner case including apparatus for conducting a log in the borehole disposed within said capsule, said inner case having a first support shaft at one end thereof and a second support shaft at the opposite end thereof, and means for supporting said inner case within said capsule so as to permit said inner case to be freely rotatable therein about the longitudinal axis thereof, said supporting means including first and second thrust bearings disposed within said first and second caps respectively and adapted to receive the first and second shafts respectively of said inner case, said supporting means providing predetermined clearance for expansion of said inner case when operated over a predetermined temperature range, and a compression spring disposed within said first cap and oriented to apply a force on the end of the support shaft along the longitudinal axis of the inner case, and an end thrust bearing disposed within said first cap between the end of said first shaft and said compression spring.

5. Apparatus as defined in claim 4 wherein said first shaft is provided with a shoulder and which further includes a washer having a given thickness and disposed on said first shaft between said first thrust bearing and said shoulder of said shaft.

6. Apparatus for well surveying comprising a tubular member adapted to be inserted in a rotatable drill string, a housing disposed within said tubular member so as to provide a fluid passage through said tubular member, logging equipment disposed within said housing and means for mounting said housing within said tubular member for substantially free rotation therein about the longitudinal axis of said tubular member, said mounting means providing predetermined clearance for expansion of said inner case along said longitudinal axis when operated over a predetermined temperature range, said mounting means further including resilient means comprising a spring mounted in compressional relationship between said capsule and said inner case and being oriented to apply pressure between said capsule and said inner case along said longitudinal axis thereby comprising means for opposing movement of said housing along the longitudinal axis of and with respect to said tubular member thereby substantially to eliminate longitudinal chatter while maintaining said housing freely rotatable.

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