June 10, 1969 M. P. LEBOURG 3,448,612

METHOD OF AND APPARATUS FOR TRANSMITTING INFORMATION FROM A SUBSURFACE WELL TOOL TO THE EARTH'S SURFACE

Filed Jan. 8, 1968 Sheet 1 of 3

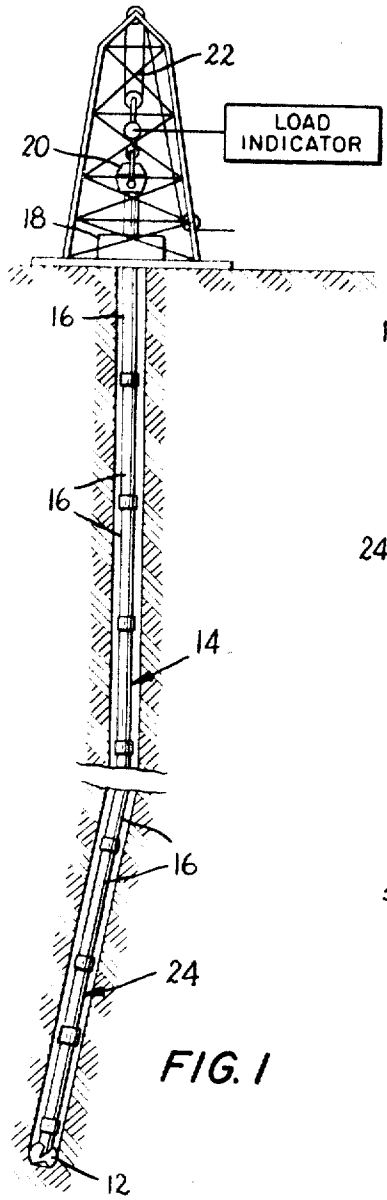


FIG. 1

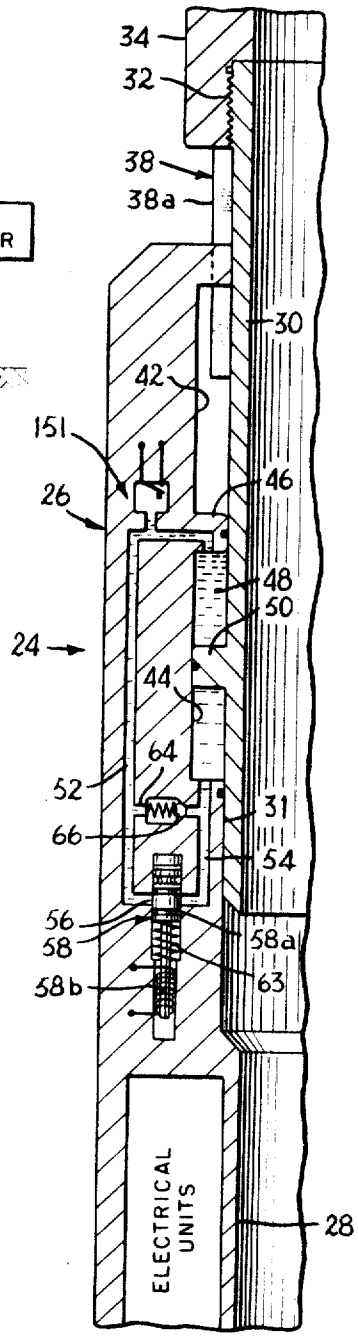


FIG. 2A

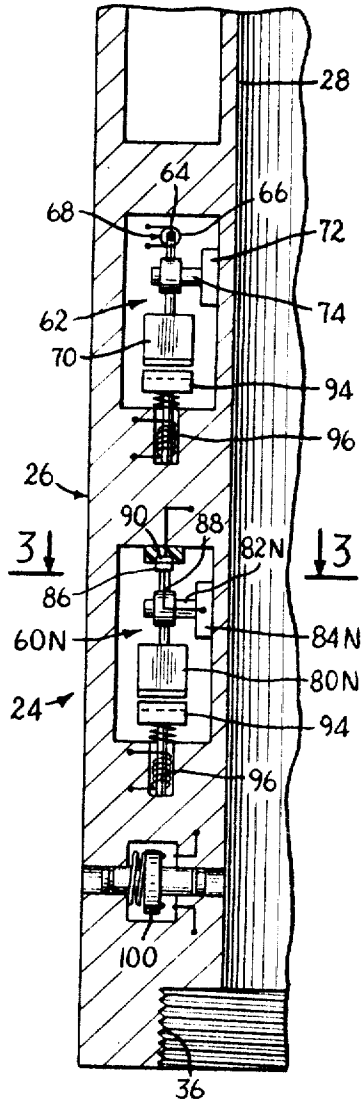


FIG. 2B

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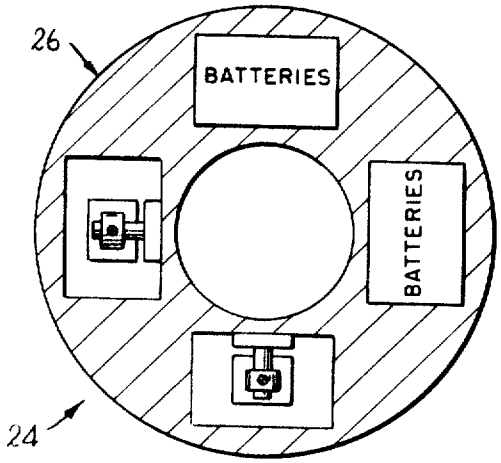


FIG. 3

FIG. 4

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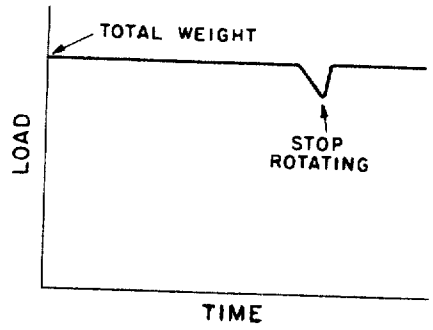


FIG. 5

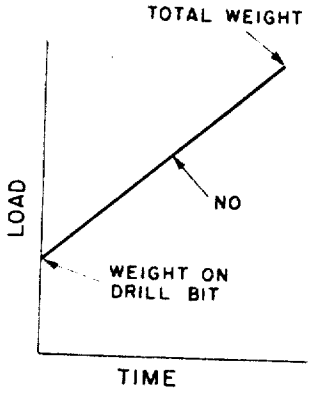


FIG. 6A

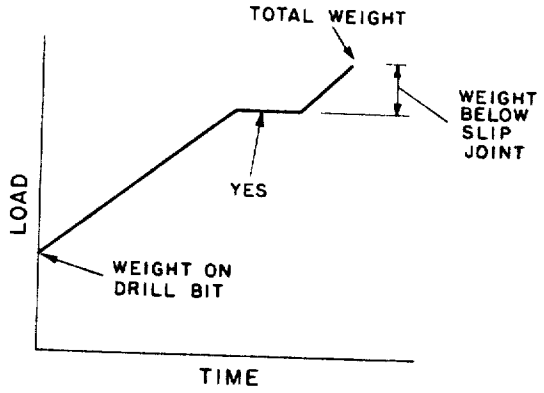


FIG. 6B

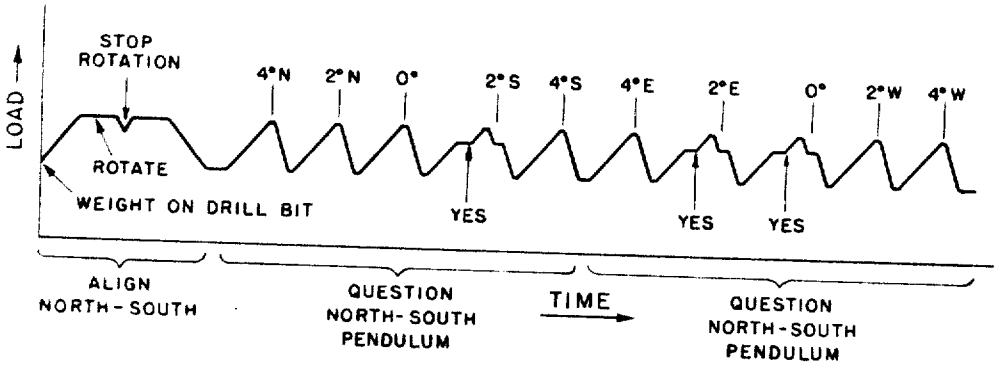


FIG. 7

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METHOD OF AND APPARATUS FOR TRANSMITTING INFORMATION FROM A SUBSURFACE WELL TOOL TO THE EARTH'S SURFACE

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U.S. Cl. 73—151 21 Claims

ABSTRACT OF THE DISCLOSURE

Information on a downhole condition in a well bore detected by a tool lowered into the well bore on a cable or pipe string is transmitted to the surface in the form of changes in the load or distance moved as a function of time occurring upon movement of or efforts to move the cable or pipe up or down the well. The information detected by the tool is produced in or appropriately transferred into the form of digital ("yes-no") signals which are used to selectively arrest relative movement between the tool and cable or pipe through a lost motion coupling. The relative movement or lack of it is evident in the continuously measured and indicated load or rate of movement of the cable or pipe string as a change in load, in the rate of change of load (time-load), or of the distance the cable or pipe moves as related to time and load.

Background of the invention

This invention relates to a method of and apparatus for transmitting information detected by a downhole well tool from the tool to the earth's surface.

There are many operations performed in a well bore throughout the various stages of drilling it, placing it into production and producing from it in which it is desirable or necessary to transmit information on one or more measurements conducted in the well from a downhole instrument or tool to the earth's surface. In some instances, the downhole tool includes recording equipment for making a record of the measurements, the information then being brought to the surface in the form of the record made by the tool at such time as the tool may be brought to the surface. In other instances, the information is transmitted to the surface immediately upon measurement by means of electrical signals transmitted through an electrical cable extending from the earth's surface to the tool.

The various systems known in the art for transmitting information from a well tool to the earth's surface have, of course, various advantages and disadvantages. For example, the use of a recording instrument in the downhole tool itself has the advantage of not requiring any transmission instrumentality between the tool in the earth's surface but at the same time has the disadvantage of making the information unavailable until such time as the tool is removed from the well. The use of an electrical cable to transmit electrical signals from the tool to the earth's surface has the advantage of providing the information at the well surface promptly upon measurement in the well, as well as the advantage of permitting a great deal of information to be transmitted and appropriately recorded by equipment at the earth's surface, but it has the disadvantage of not being conveniently adaptable to well tools that are employed with tubing or pipe strings in the well.

Summary of the invention

There is provided, in accordance with the present invention, an information transmitting system in which

measurements of various sorts by a tool lowered into the well bore on either a cable or a pipe string is transmitted to the surface in the form of changes, as a function of time, in the load carried by or the distance travelled by the cable or pipe as it is moved up or down the well or upon efforts to move it. The measurements of the tool are appropriately transferred into the form of digital ("yes-no") signals which are used to selectively arrest relative movement between the tool and the cable or pipe string, the relative movement being afforded by a lost motion coupling between the tool and the cable or pipe. The relative movement or lack of it is evident in the continuously measured and indicated load carried by or the rate of movement of the cable or pipe string as a change in load, in rate of change in load, or in the distance travelled by the cable or pipe as related to time.

More particularly, an exemplary apparatus embodying the information transmitting system of the invention comprises a lost motion coupling between the member and the tool and a suitable mechanism for selectively arresting or permitting the relative movement of the elements of the lost motion coupling, the mechanism being operated by digital signals indicative of the information measured by the well tool. For example, if the tool is of the type that by suitable manipulation can be anchored against upward movement in the well bore, a tension may be applied at the surface on the cable or pipe string and the mechanism in the lost motion controlled to vary the tension and thus indicate either a "yes" or a "no" by the time duration of each tension variation. A longer decrease in tension may for example indicate a "yes," while a shorter decrease in tension may indicate a "no," the changes in tension in each case being initiated by permitting relative movement between the tool and the pipe or cable through the lost motion in connection. Similarly, a "yes" or "no" signal may be indicated by the magnitude of movement during a given time of the cable or pipe string. The movements or tendencies for movements may be cyclical, and one or more bits of information can be transmitted during each cycle. The lost motion provided by the coupling may be rotational, axial, or a combination.

The specific lost motion coupling between the tool and pipe string or cable can take various forms, as can the mechanism by which its movement is selectively arrested or permitted. For example, the arresting device may be a friction clutch, a ratchet device, a hydraulic mechanism and so forth. Furthermore, the particular way in which the measurements by the tool is produced or converted into digital signals controlling the lost motion coupling can also be of various forms, including various types of electronic, electrical or electro-mechanical digital converters.

In one embodiment, the lost motion coupling may take the form of a cylinder and piston, the cylinder being, in general, most conveniently provided on the well tool and the piston being coupled to the tubing string or cable (although the reverse is quite possible). The cylinder is filled with fluid, and in order to selectively arrest or permit movement of the piston through the cylinder, a bypass communicating the parts of the cylinder on opposite sides of the piston with each other and having a suitably controlled valve is provided. The valve is controlled by digital signals representing the measurements by the tool. Instead of providing a hydraulic system in the lost motion coupling a suitable mechanical brake or clutch can be employed, the brake or clutch being controlled, in a manner similar to the bypass valve, by digital signals representing the measurements.

When the cable or pipe string is moved to move the tool and the movement of the tool is appropriately arrested by being anchored in the well bore or by virtue

of the gravity forces of its weight, thereby placing the pipe string or cable under tension, the movement of the cable or pipe string relative to the tool is selectively arrested or permitted by operation of the hydraulic or mechanical arresting device, the arresting device being controlled by the measurements made by the tool. Accordingly, the load carried by the cable or pipe string or the distance that it moves, as a function of time, is changed depending upon whether the lost motion is arrested or permitted, and by continuously detecting and indicating the load carried by or the movement of the pipe string or cable at the well surface, the digital signals are obtained and can be interpreted to obtain the information measured by the downhole tool.

The information transmitting system of the invention offers a number of important advantages. For one thing, it is adapted for use with both tools used with cables and those used with pipe strings. Further, it provides the detected information at the earth's surface relatively promptly, usually within minutes or seconds of a measurement, as compared to the delay required with recording type tools. It does not require a conductor cable or other special transmission element other than the member by which it is lowered into and manipulated in the well. The invention can be used with relatively simple monitoring and recording equipment at the surface and, in fact, in many instances requires only the normal load indicator used with the well rig. The system is well adapted to uses in which the well tool forms a part of other equipment being used in a well and thus may remain in the well for relatively long periods of time; in these cases, measurements may be made from time to time, as may be desired, without having to run the tool into the well, perform the operation and retrieve it, as is the case with many well tools.

Description of the drawings

For a better understanding of the invention, reference may be made to the following description of an exemplary embodiment, taken in conjunction with the figures of the accompanying drawings, in which:

FIG. 1 is a schematic view taken in section through the earth generally along the axis of a well bore having drilling equipment in place;

FIGS. 2A and 2B, taken end to end one over the other in that order, constitute a side view in cross section of a well tool embodying one form of the information transmitting system;

FIG. 3 is an end view in section of the tool of FIGS. 2A and 2B, the section being taken generally along a plane indicated by the lines 3—3 of FIG. 2B and in the direction of the arrows;

FIG. 4 is a schematic representation of the tool of FIGS. 2A, 2B and 3 and a circiut diagram of electrical equipment contained in the tool; and

FIGS. 5, 6A, 6B and 7 are representative plots of the load of the downhole equipment, as a function of time, taken during manipulation of the tubing string to obtain information from the tool.

Description of exemplary embodiment

The information transmitting system of the invention, as depicted in the drawings and described in detail below, is embodied in a well tool that is used to detect, at any time during the drilling of a well bore, the azimuth and inclination of the well bore. As is well known to those skilled in the art, it is important, while drilling a well, to know the path that the well bore takes as it proceeds into the earth. In most cases, the earth formations to which the drill is to penetrate are located vertically below the drilling rig, but not infrequently, drilled holes may not proceed along a true vertical path but follow random paths because of varying sub-surface conditions. On the other hand, there are many cases in which the target earth formation is displaced a substantial distance from a vertical axis through the drill rig and a so-called slant well bore must be formed by purposely deviating the drilling direction from the vertical at a prescribed azimuth and inclination. In either case, it is important to determine from time to time the direction in which the drilled hole is proceeding so that any excessive deviation from a desired path can be corrected.

Referring now to FIG. 1, a typical rotary drilling operation is carried out by means of equipment that includes a drill **12** carried at the bottom of a drill pipe string **14** made up of a plurality of lengths or sections **16** of drill pipe supported from the earth's surface on a derrick. The pipe string **14**, and therefore the drill **12**, are rotated by a rotary table **18** at the well head which is driven by a suitable power train (not shown). The pipe string is supported by a swivel **20** suspended from a cable block and tackle mechanism **22** which, of course, can be raised and lowered to correspondingly raise and lower the pipe string. The swivel **20** includes a suitable arrangement by which drilling mud may be pumped down through the pipe string, the mud circulating back up the annulus between the pipe string and the well bore to carry away the cuttings.

As the drilling proceeds, the pipe string is lowered, and when a new pipe section is needed to go farther, the swivel is disconnected from the top pipe section, raised, and another pipe section installed at the top of the pipe string. For purposes of representing the operation of the deviation detection tool, which is installed at any appropriate distance above the drill bit **12** and is designated generally in the drawings by the reference numeral **24**, the well bore is shown to have deviated at a substantial angle or inclination relative to a desired vertical path. As is well known to those skilled in the art, upon detection of a deviation from the prescribed path, corrective steps can be taken so that the desired target formation can be ultimately drilled to despite periodic deviations.

Referring next to FIGS. 2A, 2B and 3, the deviation detection tool **24** includes a generally tubular body **26**, which may be formed of a number of sections (not shown) appropriately threaded or otherwise joined together to permit the tool to be easily assembled and disassembled, initially or for subsequent maintenance and repair. The body **26** is formed with an axial bore **28** extending its entire length, the bore serving to conduct drilling mud down through the tool. The upper end of the tool is adapted to be coupled to the pipe string sections above it by means of a lost motion coupling constituted by a cylindrical sleeve member **30** slidably received within an enlarged portion **31** of the central bore **28**. The sleeve **30** is threaded at its upper end **32** to receive a coupling element **34** by which it can be connected to the pipe string section next above it and is rotatably coupled to the body by means of a splined connection **38** so that rotation of the pipe string is transmitted to the tool body while relative axial movement between the sleeve **30** and body **26** is permitted. At the lower end of the body (FIG. 2B) is an internal thread **36** by which a drill pipe section or a drilling collar below the tool can be connected to the tool and thus to the pipe string **14**.

Formed in the upper portion of the tool body **26** are two enlarged bores **42** and **44**, the bores being separated by an inwardly extending annular flange **46**. The upper bore **42** serves as a cavity through which the splines **38***a* on the lost motion sleeve **30** can move, while the lower bore **44** defines the outer wall of a hydraulic cylinder **48**. The inner wall of the cylinder **48** is constituted by the outer surface of the sleeve **30**. The cylinder **48** is filled with a suitable liquid and is divided into upper and lower parts of variable volume by an outwardly extending flange **50** on the sleeve **30**, the flange **50** constituting a piston and being movable with the sleeve along the cylinder **48**. Appropriate seals, such as the several O-ring seals shown in FIG. 2A, are provided to seal the body to the sleeve and the piston to the outer cylinder wall.

The parts of the cylinder **48** on either side of the flange or piston **50** are communicated with each other by two bypass passages, the two passages having, however, common branches **52** and **54** leading from the upper and lower parts, respectively, of the cylinder **48**. Located in one of the bypass passage branches, and particularly in a branch **56**, is a solenoid valve **58** which includes a valve member **58***a* adapted to be moved to either open or close the branch **56** and an electro-magnetic coil **58***b*. The valve element **58***a* is spring-loaded by a spring **63** so that it normally closes the bypass passage branch **56** to prevent communication between the two cylinder parts, but upon energization of the electro-magnetic coil **58***b*, the valve element **58***a* is moved against the spring **63** to open the bypass branch **56**. The other bypass passage between the two parts of the cylinder is constituted by a branch **64** which is equipped with a one way valve **66** so that the hydraulic fluid in the cylinder **48** can move from the part of the cylinder **48** below the piston **50** into the upper part of the cylinder upon downward movement of the sleeve **30**, while flow of hydraulic fluid from the upper part to the lower part of the cylinder upon upward movement of the sleeve **30** is precluded.

To define fully the deviation of the well bore from a predetermined desired path, it is necessary to know (1) the angle between the desired axis and the axis of the bore as drilled and (2) the angle between a given vertical reference plane and a vertical plane through the axis of the bore. Regardless of whether the well is to be drilled precisely vertically or at a slant in a given direction, the deviation can be computed if (1) the inclination of the well bore axis relative to the true vertical and (2) the azimuth of a vertical plane through the well bore axis are known. These factors can, in turn, be determined by measuring the inclination of the well bore axis in two vertical planes, the azimuths of both of which are known, and computing the resultant angle of inclination and azimuth.

The deviation tool **24** provides inclination measurements in two mutually perpendicular planes by means of pendulum detectors **60N** and **60E**. (The letter designations N and E, as is more apparent from the description to follow, relate to the direction of the vertical planes in which the measurements are made by the respective pendulum unit, the pendulum unit **60N** measuring the inclination of the tool in the north-south plane and pendulum **60E** measuring the inclination of the tool in an east-west plane.) In order that the north-south and east-west alignments of the pendulum units **60N** and **60E** are established before the measurements are made, the tool further includes an azimuth detector unit **62**. The inclination measuring pendulum units **60N** and **60E** and the azimuth detector unit **62** are located in appropriate closed chambers formed in the tool body **26**. The tool further includes closed chambers for the electrical unit (described below) and for batteries to power the electrical unit, as indicated by the captions of FIGS. 2A, 2B and 3.

The azimuth detector unit **62**, by which the tool is aligned rotationally so that the pendulum units **60N** and **60E** are able to make measurements in planes of known azimuths, utilizes the earth's natural magnetic field as a reference. This unit is per se of a type well known to those skilled in the art. An element of the unit **62** is a rod **64** of magnetic material wound with one or more sensing coils **66**, this element being sometimes referred to, and being hereinafter referred to, as a flux gate and being designated generally by the reference numeral **68**. The flux gate **68** is mounted on a pendulum **70** which is appropriately mounted, such as by a bracket **72**, for rotation about a fixed axis constituted by a shaft **74** on the bracket **72**. Although the flux gate **68** is shown schematically in the drawings (see FIG. 4) to be positioned so that it assumes a horizontal orientation with the pendulum aligned vertically, it will be understood that the flux gate in practice will be mounted on the pendulum **70** such that its axis will be inclined to conform to the known inclination of the earth's magnetic flux lines for the region in which the tool is used. If a directional bit device is utilized, its direction can be oriented relative to a given pendulum and flux gate for an indicaton of the relative position of the bit in a well bore.

Referring briefly to FIG. 4 of the drawing, the flux gate **68** is coupled to a flux gate detector unit **76** which includes circuits for sensing changes in the flux field in the flux gate and in particular the maxium flux field, which is indicative of alignment of the flux gate parallel to the earth's magnetic field. As described in more detail below, the tool is rotated about its axis, and simultaneously the flux gate detector **78** senses the maximum flux condition that exists when the flux gate is parallel to the earth's magnetic field and produces a signal indicative of that condition. At that point, the rotation of the tool is stopped and therefore the tool is then known to be positioned at a predetermined rotational orientation such that the inclination detector units **60N** and **60E** detect the inclination of the tool axis in two planes, the azimuths of which are known.

The inclination detector units **60N** and **60E** are of substantially identical construction. Accordingly, the same reference numerals are applied to each, but with letter suffixes "N" or "E" to refer to a given one, where needed. Each inclination unit includes a pendulum **80** mounted for rotation on a shaft **82** carried by bracket **84** affixed to the tool body. At the upper end of the pendulum **80** is an electrical contact **86** which is coupled to a conductor **88** that is appropriately conducted away from the electrical contact, such as by being led into a slip ring on the shaft **82** and an appropriate electrical conductor led through and out of the shaft. The electrical contact **86** may, desirably, be lightly spring-loaded in an upward direction and so as to make firm contact with one of a plurality of electrical contacts **90** (see FIG. 4) carried by a contact mounting block **92** of non-conductive material affixed to the tool body. The contacts **90** are uniformly spaced apart and are positioned along an arc having its center of curvature at the axis of rotation of the pendulum **80**. Accordingly, the contact **88** on the pendulum sweeps along the arc and makes contact with one of two of the fixed contacts **90**. In this regard, the width of the pendulum contact **88** may be such that it spans the space between two of the fixed contacts **90** when the center of the contact **86** is at any point within the central one-half of the space between the contacts **90**, thereby to indicate intermediate positions, as described below.

The several fixed contacts **90** are spaced apart at known angular intervals relative to the axis of rotation of the pendulum so that center-to-center contact of the movable pendulum contact **86** with a given one of the fixed contacts **90** is indicative of a predetermined angle between the vertical axis assumed by the pendulum and the axis of the tool. Referring briefly to FIG. 4, the exemplary embodiment is shown to include five fixed contacts **90** with the center contact located in a radial-axial plane of the tool which also includes the axis of rotation of the pendulum, as constituted by the shaft **82**. Thus, the center contact indicates a zero inclination of the tool axis by contact with the movable contact **86** on the pendulum **80**. The remaining contacts **90** are uniformly spaced on each side of the center or zero contact. An electrical contact with each one exclusively by the movable contact **86** indicates a predetermined angle of inclination as established by the angular spacing of the contacts relative to the rotational axis of the pendulum. The dimensions of the contacts **86** and **90** and the spacing of the contacts **90** in the manner described at the end of the preceding paragraph, permits detection of angles of inclination intermediate those indicated by centers of the fixed contacts **90**, the intermediate inclinations being indicated when the movable contact **86** on the pendulum engages two adjacent fixed contacts **90**.

The pendulum **70** of the azimuth indicator unit **62** and those (**80**) of the inclination detector units **60N** and **60E** are normally locked in fixed positions by spring-loaded lock shoe elements **94** which are appropriately arranged to be moved out of locking engagement, such as by means of solenoids **96**. By forming the lower ends of the pendulums **80** and the engaging faces of the lock shoes **94** with curvatures having their centers at the axis of rotation of the pendulums, locking is ensured regardless of the position that the pendulums assume at any given time.

The remaining elements of the tool may be best understood in conjunction with the following description of how the tool operates.

As mentioned previously the tool **24** is located one or two drill pipe sections above the drill bit **12** (FIG. 1) and remains in the well during the drilling operation. When the drill is operating, the lock shoes **94** engage the pendulums so that they remain stationary and are not subject to being damaged as the drill pipe is rotated and otherwise manipulated in the well bore. At such time as it may be desired to determine whether there has been any deviation of the well bore from the proper alignment, the circulation of drilling mud down the drill pipe string **16** and back up through the annulus is terminated by shutting down the pump. This in turn causes the pressure differential between the inside of the tubing string and the annulus to change, the pressure within the tubing string being somewhat higher than the pressure in the annulus when drilling mud is being circulated.

During the mud circulation, a differential pressure switch **100**, which is installed in the tool body in a manner by which it is in communication with the annulus outside the tool body and the tool bore **28** (see FIGS. 2B and 4) is held open by the higher pressure in the tool bore, but upon equalization of the pressure within the tool bore with the pressure in the annulus, the pressure switch **100** closes and completes an electrical circuit across a battery **102** through conductors **104** and **106** to the motor **108** of a timer **110** and through a conductor **112** back to the other side of the battery **102**. As represented schematically in FIG. 4, the timer **110** includes a movable contact **114** which is connected by a conductor **116** and conductors **106** and **104** to one side of the battery **102** and is driven by the motor **108** in a clockwise direction beginning from the reset position shown in FIG. 4. Upon start-up the timer movable contact **114** moves first onto a fixed contact **118** and thereby completes a circuit through conductors **120**, **122** and **124** to the solenoids **96** of the pendulum lock shoes **94**, thereby withdrawing the lock shoes from engagement with the pendulums **70** and **80** of the azimuth detector unit **62** and the inclination detector units **60N** and **60E** so that the pendulums are free to assume a vertical position.

In FIG. 4 and in this written description of the structure and operation of the electrical unit of the tool, the east-west inclination detector unit **60E** is not shown or described, inasmuch as its structure and the way in which it operates are identical to those of the north-south inclination detector unit **60N**. It will, therefore, be understood that the pendulum **80** associated with the east-west inclination detector **60E** is unlocked by connecting the solenoid associated with its lock shoe element to the timer contact **118**. The circuits to the solenoids **96** are completed to the negative side of the battery through conductors **126** and **128** and the main negative conductor **112**.

At the same time that a circuit is completed to the solenoids to release the pendulum, a circuit is completed from the positive side of the battery through conductor **104**, across the switch **100** (which it should be mentioned, remains closed as long as the drilling mud pump is shut down) through conductors **106**, **116**, the movable contact **114**, and conductor **120** to the flux gate detector **76** and back to the negative side of the battery **102** through conductors **130** and main negative conductor **112**. This provides power to the flux gate detector so that during the dwell time of the timer movable contact **114** at fixed contact **118**, the tool can be manipulated in the well bore to align the flux gate **68** of the azmiuth detector unit **62** with the earth's magnetic flux.

The manipulations carried out to rotationally orient the tool include first lowering the pipe string **116** at the earth's surface so that at least the elements of the downhole equipment below the lost motion coupling of the tool are supported on the bottom of the well bore and the lost motion coupling sleeve **30** and its piston **50** are moved to their lowermost positions in the tool body. The downward movement of the lost motion coupling sleeve **30** is readily afforded by the bypass of hydraulic fluid from the lower part of the hydraulic cylinder **48** through the bypass passage **64** by the opening of the one-way valve **66** in response to pressure upon downward movement of the piston **50**. The fact that the weight of the tool and other elements below the lost motion coupling, plus any additional weight to insure that the lost motion sleeve **30** is moved to its bottom position in the tool, is verified by the reading on the load indicator at the well surface.

The second step is to pick up the pipe string so that all weight is removed from the bottom of the well bore, and when the total load is indicated by the load indicator, to rotate slowly the pipe string and therefore the tool **24**. When the pipe string **16** is picked up to raise the drilling tool off the bottom and to support the entire weight of the equipment from the derrick, there is no opportunity for movement of the lost motion sleeve **30** and its piston **50** upwardly through the hydraulic cylinder **48** inasmuch as the bypass control valve **58** is in its normally closed position (as described above). Accordingly, the hydraulic fluid in the upper part of the cylinder **48** above the piston **50** constitutes, in effect, a rigid connection between the portion of the pipe string **16** above the lost motion coupling and the parts of the equipment below the lost motion coupling.

As the tool is slowly rotated by rotating the pipe string at the well surface, the flux gate **68** of the azimuth detector unit **62** senses the change in flux density in the core rod **64** as the orientation of the rod changes relative to the earth's magnetic flux lines. When the tool is oriented such that the flux gate is aligned with the earth's magnetic flux lines, the flux gate detector produces a signal indicative of that condition and completes an electrical circuit across the solenoid coil **58***b* of the bypass valve **58**, through conductors **132** and **134**, thereby energizing the solenoid **58***b* and opening the bypass valve. When the bypass valve opens, the hydraulic fluid in the cylinder **48** can pass from the upper part of the cylinder above the piston **50** to the lower part, and the tool body can move downwardly by gravity force relative to the lost motion coupling sleeve **30**. Such release of the tool body relative to the lost motion sleeve is indicated at the well surface by a drop in the load indicated by the indicator at the surface.

FIG. 5 depicts a typical curve of the load plotted against time during the procedure followed to align the tool so that the plane of movement of the pendulums **70** and **80N** of the azimuth indicator **62** and the inclination detector unit **60N** is parallel to the earth's magnetic flux field. When the drop in weight is indicated on the load indicator, the rotation of the pipe string **16** is stopped, and since the weight drop was initiated at the point when the flux gate **68** was aligned with the earth's magnetic flux, the tool then has been stopped in the position in which the azimuths of the inclination detectors are known, the north-south inclination detector **60N** being in position to detect the inclination of the tool in a vertical north-south (magnetic) plane and the east-west detector position to detect the inclination in a vertical east-west plane. It will be clear that even though the axis of rotation of the respective pendulums may be inclined by virtue of an inclination of the axis of the tool, the angles that they measure can be projected into mutually perpendicular planes having north-south and

east-west azimuths, relative to magnetic north. The contact **118** on the timer **110** will provide an appropriate time duration within which the alignment of the tool can be readily completed.

With the tool now oriented to measure inclination along two mutually perpendicular axes of known azimuths and upon completion of the stage of operation of the timer in which the movable contact **114** dwells on the fixed contact **118**, the movement of the movable timer contact **114** out of engagement with the fixed contact **118** breaks the circuits to the pendulum lock shoe solenoids **96**, thereby locking the pendulums in vertical positions, and the circuit to the flux gate detector unit **76**, thereby deenergizing the bypass valve solenoid **62** and closing the bypass passage **56**. The locking of the pendulums of the inclination detector units **60N** and **60E**, in effect, stores the information that they provide on the inclination of the axis of the tool.

Next, the movable contact **114** of the timer moves onto a fixed contact **120** which completes a circuit from the positive side of the battery **102**, through a conductor **136**, across the reset coil **138** of a step relay **140** and through a conductor **142** and the conductor **112** back to the negative side of the battery. Upon energization of the reset coil **138**, the step relay is reset to the position, as illustrated schematically in FIG. 4, in which its movable contact **144** is ready to cycle through a series of fixed contacts **146**, each of which is connected to one of the fixed contacts **90** on the inclination detector unit **60N**. Meanwhile, the pendulum **80** of the inclination detector unit is, as mentioned above, in a vertical position and makes contact with one of the fixed contact elements **90** (or perhaps two adjacent contacts).

Between the time that the timer movable contact **114** leaves contact **120** and moves on to a fixed contact **144**, the pipe string is again lowered to the bottom of the well bore so that the lost motion coupling sleeve **30** is moved down relative to the tool body to its lowermost position and the weight of the tool and all parts below it plus a part of the weight of the pipe string above the tool are supported on the bottom of the well bore rather than from the derrick. With the stepping relay **140** thus set and the pendulums locked in position, as described above, the tool is now in readiness for the transmission of information on the inclination of the tool to the well surface.

The transmission procedure may begin as soon as the movable contact **114** of the timer **110** engages a fixed timer contact **160**, thereby completing a circuit from the plus side of the battery through conductor **104**, pressure switch **100**, conductors **106** and **116**, the timer, and the conductor **126**, to the contact **86** carried by the pendulum **80** of the inclination detector unit **60N**. The fixed contacts **90** of the unit **60N** are, it will be noted, connected to the fixed contacts **146** of the relay and are thus arranged to be connected in sequence to the negative side of the battery through a circuit comprising the movable relay contact **144**, a conductor **162**, the solenoid coil **58***b* of the bypass valve **58** and conductors **164** and **112**.

The process of obtaining information on the inclination of the tool at the well surface involves "questioning" the tool by raising and lowering the pipe string. When the pipe string **14** is lowered so that a portion of the weight of the equipment in the well bore is supported on the bottom of the hole, the lost motion sleeve **30** is in its lowermost position, and each questioning step consists of first lowering the pipe to that extent and then slowly raising it, preferably at a uniform rate, thereby gradually lifting the weight carried by the drill bit and transferring it to the pipe string. As the pipe string is gradually raised, the weight indicated by the load indicator increases proportionately, the weight increase being gradual by virtue of the elongation of the pipe string. In other words, raising the pipe string does not merely pick up all of the weight of the equipment in the well at one time but picks up the weight gradually, because the elongation under tensile stresses of the pipe string leaves a part of the equipment on the bottom while the remainder is gradually picked up. Accordingly, referring to FIG. *5a*, the plot of load against time is substantially a straight sloping line.

With the stepping relay **140** in the reset position shown in FIG. 4, then, the rightmost fixed contact **90** (as illustrated in FIG. 4) of the inclination detector is questioned. To do so, the pipe string is raised, and because the stepping relay is on the reset position and the bypass valve **58** is therefore deenergized and closed, the fluid in the lost motion cylinder **48** at first acts as rigid coupling so that the tool tends to be picked up off the bottom of the well bore, and the weight of the equipment below the lost motion coupling exerts a downward force that pressurizes the fluid in the upper part of the cylinder **48**. The creation of pressure in the cylinder closes a pressure switch **151** that is in communication with the upper part of the cylinder (see FIGS. 2A and 4) and is located in a circuit across the battery **102** comprising conductors **104** and **106**, timer contact **160**, a conductor **152**, the stepping relay coil **153** of the relay **140**, and conductors **154**, **155** and **112**. When the switch **151** closes, the stepping coil **153** is energized and shifts the movable relay contact **144** to the first of the series of fixed contacts **146**.

When the circuit across the first relay contact **146** is not completed because the movable contact **86** of the inclination detector is not in engagement with the corresponding fixed contact (the situation depicted in FIG. 4), the bypass valve **58** remains closed, and the parts of the equipment in the well below the lost-motion coupling are raised from the bottom of the hole just as if the lost-motion coupling did not exist.

The questioning procedure described above is repeated, each questioning step involving lowering the tool to support a portion of the downhole equipment on the bottom of the hole followed by slowly raising the pipe string. Upon each upward movement of the pipe string, the stepping coil **152** is energized and moves the movable contact **144** of the stepping relay **140** to the next succeeding fixed contact. As each relay contact is questioned, it indicates whether or not a circuit is completed, and therefore whether or not the movable contact on the pendulum is engaging the fixed contact of the unit to which it is connected, by the shape of the load to time plot. As in the sequence just described pertaining to the first stepping relay contact **146**, a "no" indication is given by the absence of any break in the substantially straight, load-time curve, as represented by FIG. 6A.

A "yes" indication from the well tool is indicated by a break in the load-time curve, that is by a period of no load increase, as well as by an increase in the time taken to reach a maximum load beginning at a given weight indication. More particularly, let us assume that the questioning operation has proceeded to the point where the movable contact **144** of the stepping relay **140** has moved into engagement with the fourth contact in the sequence (FIG. 4) which is connected to the plus side of the battery by virtue of the movable pendulum contact **86** being engaged with the pendulum unit fixed contact **92** to which it is connected. Consequently, a circuit is completed to the bypass valve solenoid coil **62**, thereby energizing the bypass valve solenoid coil **58***b* and opening the bypass valve **58**. At this point the raising of the pipe string will have proceeded to the point where the tool body **26** was about to be picked up from the bottom of the well hole, and a certain time had elapsed from the point of time at which the pipe was first raised to take weight off the drill bit (see FIG. 6B). As the pipe string is gradually raised further, however, the lost-motion coupling sleeve **38** is relatively free to move upwardly through the cylinder **48**, inasmuch as the bypass passage **56** is now opened and fluid communication is

afforded between the two parts of the lost-motion cylinder **48** on either side of the piston **50**.

Accordingly, for a period of time, the upward movement of the pipe string at a constant rate does not result in a corresponding increase in the weight, thereby providing a steady load, as represented by the horizontal portion of the time load to time plot of FIG. 6B. This portion of the load line may be commonly referred to in this art as a "free point." As soon as the lost-motion coupling sleeve **30** reaches its highest position, which is established by engagement of the upper face of the piston **50** with the top shoulder of the cylinder **48**, the weight of the tool and the elements of the equipment below it are picked up, and the load increases to the maximum. The "yes" signal transmitted to the earth's surface is indicated by the break in the time-load curve and the total time taken to raise the equipment off the bottom of the hole. It is also indicated by the distance through which the pipe string is moved to lift the total downhole load off the bottom, a greater distance being required when a "yes" signal is transmitted because of the lost motion.

When the north-south inclination detector **60N** has been questioned completely by stepping through all of the fixed contacts in the manner described above, a procedure which actually can be accomplished in a relatively short period of time and in any event can be readily accomplished within the time set on the timer, the readout operations are suspended until the timer cycles to the next phase in which the movable contact **114** dwells on a fixed contact **170**. The contact **170** is equivalent to the contact **120** and energizes a reset coil of a stepping relay associated with the east-west inclination detector. (As mentioned above, the circuit components serving the east-west detector **60E** are not shown in FIG. 4 since they are substantially identical to those just described and shown in FIG. 4 serving the north-south detector **60N**.) Next, the timer cycles to a fixed contact **172**, which is equivalent to the contact **140** and is coupled to the movable contact of the stepping relay of the east-west inclination detector **60**. In exactly the same manner as described above, the east-west inclination detector unit **60N** is questioned and a load-time plot is made.

Following the dwell at contact **172** for the questioning of the east-west inclination detector, the timer moves back to its start position and is reset. The timer may be of the type which will not restart, even though it remains energized because the differential pressure switch **100** remains closed, until it is deenergized and energized again. Accordingly, the timer will not recycle until the pressure switch **100** is first opened and then closed again.

FIG. 7 is an exemplary plot of load to time as might be recorded by a recorder type load indicator for a complete series of questioning operations made to obtain a deviation reading. The plot begins with a portion of the weight of a downhole equipment carried by the drill bit, followed by raising the pipe string, then slowly rotating it until the weight drops, which indicates that the bypass valve **58** has opened and the weight of the tool has been briefly released from the pipe string above the tool. At this point rotation is stopped, and the tool held in position until the timer has completed the alignment phase of operation. The tool is then subsequently lowered and then raised slowly repeatedly, each lowering and raising providing a "yes" or "no" indication at the well surface in the form of a variation in the time-load relationship.

In the exemplary curve, three "yes" indications are depicted, one on the north-south unit of 2° south and two on the east-west unit (2° and 4° west) that are interpolated to yield a 3° west reading. The azimuth and inclination of the well bore are readily computed from these readings in a manner well known to those skilled in the art.

From the foregoing, it is apparent that the system of the invention involves the transmission of information from the downhole tool to the earth's surface in the form of a series of digital signal bits, each of which consists of a "yes" or "no" answer indicated by the load-time-distance relationship occurring upon movement of the pipe string. The measurements obtained were described in connection with azimuth and deviation, however, it should be appreciated in the broader aspects of the present invention, any kind of downhole measurement such as a measurement of formation fluid characteristics, pressure or the like can be converted from an analog form to digital to program the operation of valve **58**. It should also be apparent that measurements could be obtained while moving and subsequently transmitted when desired.

It will be readily apparent to those skilled in the art that various elements of the exemplary tool can be modified by equivalent devices of somewhat different form. For example, in the tool described above and illustrated in the drawings, the pendulum readouts include mechanical memory of the information by locking the pendulum in the position which it had assumed at the time the measurement was being made. Where transient information is being detected, it will be readily apparent to those skilled in the art that information storage, analog-to-digital conversion and readout can be accomplished by various types of electronic units, such as those commonly used in data processing and many other types of equipment. Electronic units of various types can be used to control the relative movement between the tool and the cable or pipe string by which it is supported and manipulated in the well bore in a manner generally similar to that accomplished by the exemplary equipment shown in the drawing. Accordingly, it will be understood that the above-described embodiment is merely exemplary, and those skilled in the art will be able to make numerous variations and modifications of it without departing from the spirit and scope of the invention. All such variations and modifications are intended to be included within the scope of the invention as defined in the appended claims.

I claim:

1. Well apparatus comprising a well tool adapted to be lowered into a well bore and having means thereon for providing measurements of at least one parameter, a member for lowering the well tool into the well bore, supporting it in the well bore and moving it longitudinally in the well bore, a lost motion coupling between the member and the tool including means for varying the time-load-distance relationship between the tool and the member upon movement of the member to move the tool, means on the tool for controlling the time-load-distance varying means and providing a predetermined variation in the said time-load-distance relationship in accordance with the measurement detected by the tool, and means at the earth's surface and coupled to the member for continuously monitoring the load carried by the member as an indication of said downhole parameter.

2. Well apparatus according to claim **1** wherein the lost motion coupling includes coacting relatively movable elements coupled to the member and the tool, respectively, and wherein the means for varying the time-load-distance relationship includes means for selectively permitting or precluding relative motion between the relatively movable elements of the coupling.

3. Well apparatus according to claim **2** wherein the means for selectively permitting or precluding the relative motion between the elements includes fluid pressure means.

4. Well apparatus according to claim **1** wherein the lost motion coupling includes a fluid-containing cylinder on one of the tool and the member, the cylinder being aligned generally with the axis of the tool, and a piston on the other of the member and tool and movable in the cylinder, and wherein the means for varying the time-load-distance relationship between the tool and member includes a passage bypassing the piston and communicating the parts of the cylinder on opposite sides of the piston with each other, and valve means responsive to the in-

formation detected by the detecting means for selectively blocking or opening the bypass to prevent or permit, respectively, communication between the parts of the cylinder on opposite sides of the piston thereby to prevent or permit relative motion between the piston and cylinder.

5. Well apparatus according to claim 4 further comprising a second bypass passage between the parts of the cylinder on opposite sides of the piston, and one-way valve means in the second bypass for permitting communication between the said parts in one direction only independently of the valve means in the first bypass.

6. Well apparatus according to claim 1 wherein the tool further includes means for storing the information on the down-hole condition detected by the tool, means for transposing the detected information into the digital form of a plurality of bits of "yes-no" signals, and means for sequentially delivering the signal bits to the varying means to control the time-load-distance relationship between the tool and member in response to the signal bits.

7. Well apparatus according to claim 6 wherein the means for sequentially delivering the signal bits to the varying means includes control means responsive to a predetermined movement of the member relative to the tool through the lost motion coupling.

8. Well apparatus comprising a well tool adapted to be lowered into a well bore and having means thereon for detecting a downhole parameter and producing digital signals consisting of a plurality of bits of "yes-no" signals indicative of the downhole parameter, means for storing the digital signals, a member for lowering, supporting and positioning the tool in the well bore, lost motion coupling means between the member and the tool including means responsive to the signal bits for varying the time-load-distance relationship between the tool and the member upon movement of the member to move the tool, means for sequentially releasing the signal bits to the varying means, and means at the earth's surface for continuously monitoring the load carried by the member as an indication of said downhole parameter.

9. Well apparatus according to claim 8 wherein the lost motion coupling means includes coacting relatively movable elements on the member and on the tool, and wherein the means for varying the time-load-distance relationship between the tool and member includes means cooperative with the relatively movable elements for selectively permitting or precluding movement of the member relative to the tool.

10. Well apparatus according to claim 9 wherein the means for sequentially releasing the signal bits to the varying means includes means responsive to prescribed movements of the member to move the tool.

11. Well apparatus according to claim 9 wherein the relatively movable elements of the lost motion coupling include a fluid-containing cylinder on one of the member and tool and generally aligned with the axis of the tool and a piston on the other of the member and tool and movable through the cylinder, and wherein the means for varying the time-load-distance relationship includes passage means bypassing the piston to communicate the parts of the cylinder on opposite sides of the piston with each other, and valve means for selectively blocking or opening the bypass in response to the digital signals to prevent or permit, respectively, communication between the said parts of the cylinder.

12. Well apparatus according to claim 11 wherein the means for sequentially releasing the signal bits to the varying means includes means responsive to the fluid pressure in the cylinder upon movement of the member to move the tool.

13. Well apparatus according to claim 11 wherein the varying means is operative to preclude movement of the member relative to the tool by closing the bypass in response to one of the "yes" and "no" elements of each signal bit and to permit movement of the member relative to the tool by opening the bypass in response to the sponse to one of the "yes" and "no" elements of each

14. Well apparatus according to claim 11 further comprising a second bypass passage communicating the parts of the cylinder on opposite sides of the piston and a one-way valve in the second bypass passage for restricting communication therethrough to one direction only.

15. Well apparatus according to claim 14 wherein the oneway valve permits communication of the cylinder fluid between the cylinder parts upon downward movement of the member relative to the tool only.

16. A method of transmitting to the earth's surface information on a downhole parameter detected by a well tool adapted to be lowered into the well and supported and moved therein by a member coupled to the tool through a lost motion coupling and extending to the earth's surface, the well tool having means for producing signals indicative of the downhole parameter, comprising the steps of producing digital signals consisting of a plurality of "yes-no" signal bits indicative of the information, storing the signal bits, sequentially releasing the stored signal bits and simultaneously with each release of a signal bit moving the member and altering the time-load-distance relationship between the member and the tool in accordance with the signal bit and continuously monitoring the load carried by the member as an indication of said downhole parameter.

17. A method according to claim 16 wherein the time-load-distance relationship between the tool and member is altered by selectively arresting movement of the member relative to the tool through the lost motion coupling.

18. A method according to claim 16, the method employing apparatus in which the lost motion coupling includes a fluid-containing cylinder and a piston movable in the cylinder, wherein the step of arresting the movement of the cylinder is accomplished by selectively interrupting a fluid bypass communicating parts of the cylinder on opposite sides of the piston to afford movement of the member relative to the tool, thereby to yield a surface indication in the form of a change in the measured load-time relationship as continuously measured at the well surface.

19. A method according to claim 18 wherein the step of selectively interrupting the fluid bypass is accomplished upon movement of the member relative to the tool in one direction only.

20. A method of transmitting to the earth's surface information on a downhole parameter measured by a well tool adapted to be lowered into the well and supported and moved therein by a member coupled to the tool through a lost motion coupling and extending to the earth's surface, the lost motion coupling including means for selectively arresting movement of the member relative to the tool and the tool having means for producing signals indicative of the downhole measurement, comprising the steps of producing digital signals consisting of a plurality of "yes-no" signal bits indicative of the measurement storing the signal bits, moving the member to its lowest position relative to the tool while the tool is supported independently of the member, raising the member at a substantially constant rate of upward movement and simultaneously with such movement releasing at least one signal bit and controlling the arresting means of the tool lost motion in accordance with the signal bit in a manner such that the load carried by the member as related to time differs depending upon whether the signal bit is a "yes" or a "no".

21. A well tool adapted to be lowered into and supported in a well bore by a member extending down from the earth's surface, comprising means for detecting a downhole parameter and producing digital signals consisting of a plurality of bits of "yes-no" signals indicative of the downhole parameter, means for storing the digital signals, lost motion coupling means for coupling the tool to the member and including means responsive to the

signal bits for varying the motion relationship therein upon movement of the tool relative to the member and means for sequentially releasing the signal bits to the varying means.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,448,612 Dated June 10, 1969

Inventor(s) Maurice P. Lebourg

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 14, line 2, which now reads "sponse to one of the 'yes' and 'no' elements of each" should read -- other of the "yes" and "no" elements of each signal bit. --

SIGNED AND
SEALED
NOV 4 1969

(SEAL)
Attest:

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Commissioner of Patents