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(54) **Well tool.**

(57) The depth at which a string of pipe is stuck in a well borehole is determined using a tool suspended by a logging cable (22) and comprising a tool body (18) for running in the stuck well string, the body enclosing a first electromagnetic coil (50) connected with a suitable storage capacitor (38) and switch (36) for forming a strong magnetic field at a specified depth on the stuck well string. A second electromagnetic coil (48) is included in the tool and functions as a detector means. The detected signal is output to a suitable amplifier system and a recorder (34). Upon application of stress to the well string, the amplitude of magnetic marks above the stuck location will either be reduced or substantially erased; the electromagnetic marks below the stuck points will not be reduced, and the change in detected signals by the detector means indicates the location of the well string sticking and enables location of a free point in the string.

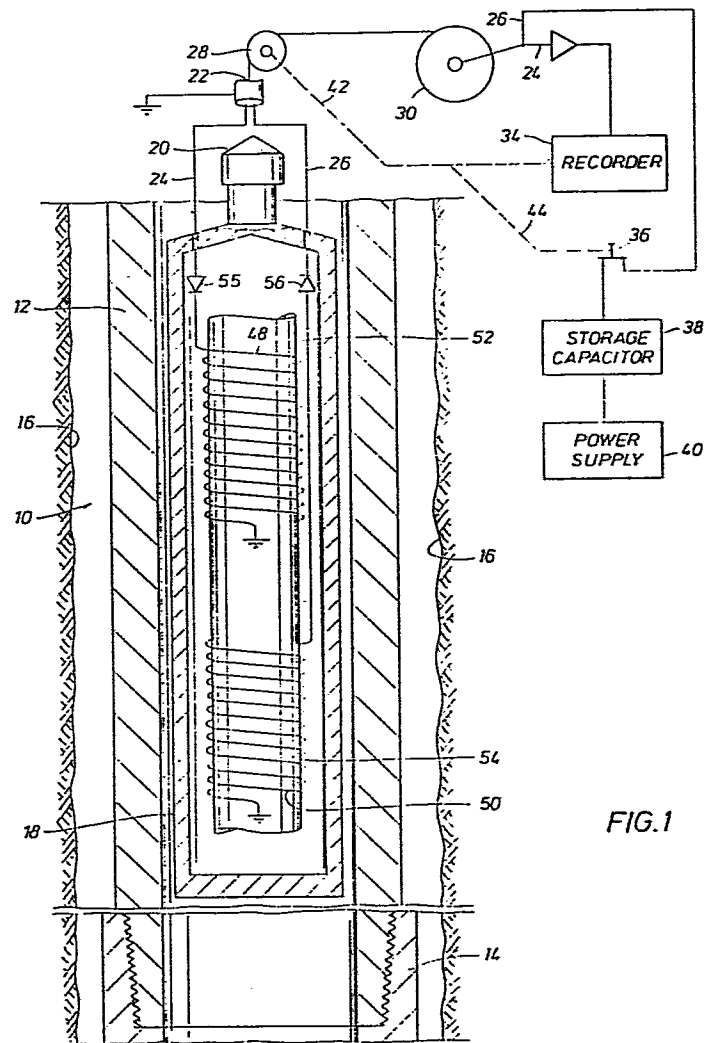


FIG. 1

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WELL TOOL

This invention relates to a well tool, particularly one for use when a pipe string is stuck in a well, to determine the position of sticking.

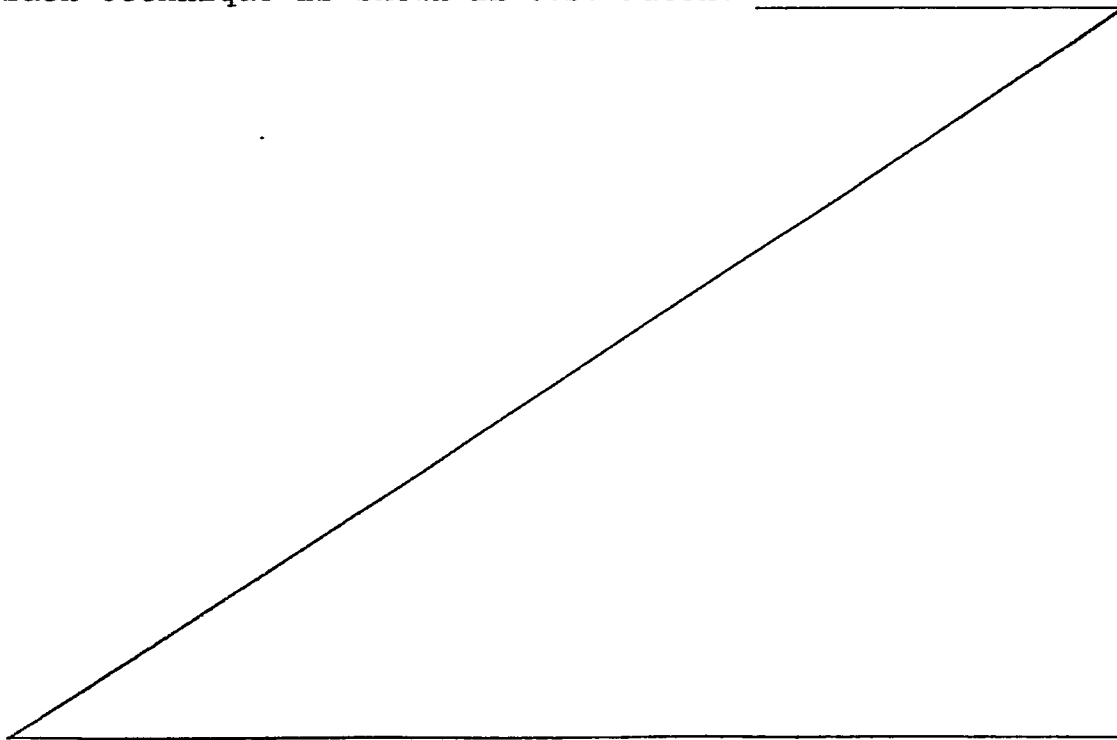
In drilling an oil or gas well, the initial
5 step is to drill a well borehole using a drill bit supported on a drill string comprised of drill collars and drill pipe. As this operation is conducted, the drill bit cuts an encircling hole surrounding the drill string. As the depth of the well increases, certain
10 formations encountered along the borehole may collapse into the well. When they do, they may plug the annular space between the borehole and the rotating string of drill pipe, which can cause the drill pipe to stick.

Also, pressure differentials between the bore-
15 hole and formations being drilled can be encountered if the drilling fluid or mud weight is not correct, and this may cause the drill string to stick. Sticking is indicated by an increase in the torque required to rotate the drill string. The increase in torque may be so great as to
20 risk twisting the drill string, thereby damaging the drill string and incurring the risk of a difficult and expensive fishing job.

Another problem which may arise involves
borehole drifts, which force the drill string to one side
25 of the borehole at a specified location. When this occurs,

the drill string will distort the circular borehole and thus define a key seat. There is a strong possibility of sticking due to pressure differentials at a key seat. In situations other than drilling, but including
5 subsequent operations with either a drill string or another string of pipe suspended in a well borehole, there is always the chance of sticking of the string of pipe at some unknown depth. Remedial operations are then required. One such remedial operation is to unthread,
10 or cut by a shaped charge or chemical cutter, the drill string at a point just above the location where it is stuck. In other words, the upper portions of the stuck string of pipe can be removed; subsequent alternate operations can then be undertaken to remove the lower
15 portions of the stuck pipe string. It is therefore very important to be able to determine the free point of the stuck string of pipe.

The art is replete with methods and apparatus for determining the free point of stuck pipe. One
20 such technique is shown in U.S. Patent _____



4,440,019. The present method and apparatus comprises an improvement over that of the single coil device shown in this patent.

5 Briefly, the tool of the present invention is placed in the stuck pipe and it is moved along the stuck pipe. A switch is operated, either as a function of time or as a function of movement of the tool along the stuck pipe string, to supply a D.C.
10 current from a current source such as a power supply and a storage capacitor to an electromagnet coil or magnetic marking means in the tool. The D.C. current pulse supplied to the marking coil causes an intense magnetic field which passes through the
15 non-magnetic tool housing and which magnetizes the surrounding pipe. This places a magnetic mark on the interior of the pipe in the form of residual magnetism. Many such marks are made on the stuck pipe string along its length. It is intended that
20 the magnetic marks be placed along the pipe string spanning the location of the point of sticking or free point. The stuck point (or free point) is traversed above and below by such magnetic marks. These magnetic marks may then be used for subsequent
25 location of the free point.

A strain is then placed on the pipe string, as for instance by applying a lifting force, or torque, or both, to the pipe. When this occurs, the lifting force or torque stresses the pipe and causes a strain, or displacement of the pipe, from the well head to the free point. This tends to reduce the magnetism intensity or even erase the magnetic marks previously placed on the pipe.

Below the free point, the magnetic marks are unaltered in intensity or amplitude because they are not exposed to the torque or lifting stress. The present apparatus incorporates a separate detection coil which can be moved along the pipe string past the multiple magnetic marks traversing the suspected free point. The detection coil forms an output voltage signal as each magnetic mark is passed. The magnetic mark signals are recorded on a suitable record medium as a function of borehole depth. On inspection, the stuck point can be located by the change in amplitude of the recorded magnetic mark signals as a function of borehole depth.

The present apparatus preferably comprises a tool lowered on a conventional wireline logging cable in the pipe string. The tool body is made of

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non-magnetic material. This enables the marking magnetic field to be coupled through the tool housing to the surrounding pipe. The tool body preferably encloses a first and a second coil.

5 The first coil functions as the electromagnetic coil marking means and the second coil functions as the magnetic marks detector means. The two separate coils are formed on ferromagnetic cores. Each coil is connected through cable
10 conductors to equipment located at the surface which includes a power supply and storage capacitor along with a switching means which furnishes a large peak current D.C. pulse to the electromagnetic coil marking means. The detector coil means senses
15 voltage signals induced therein by the magnetic marks and forms a signal output via the logging cable conductors with a suitable amplifier and a switching means connecting the signal to a recorder. The recorder can be furnished with an input signal
20 from means measuring the depth of the tool in the well so the location of the magnetic marks in the well can be ascertained and recorded as a function of borehole depth.

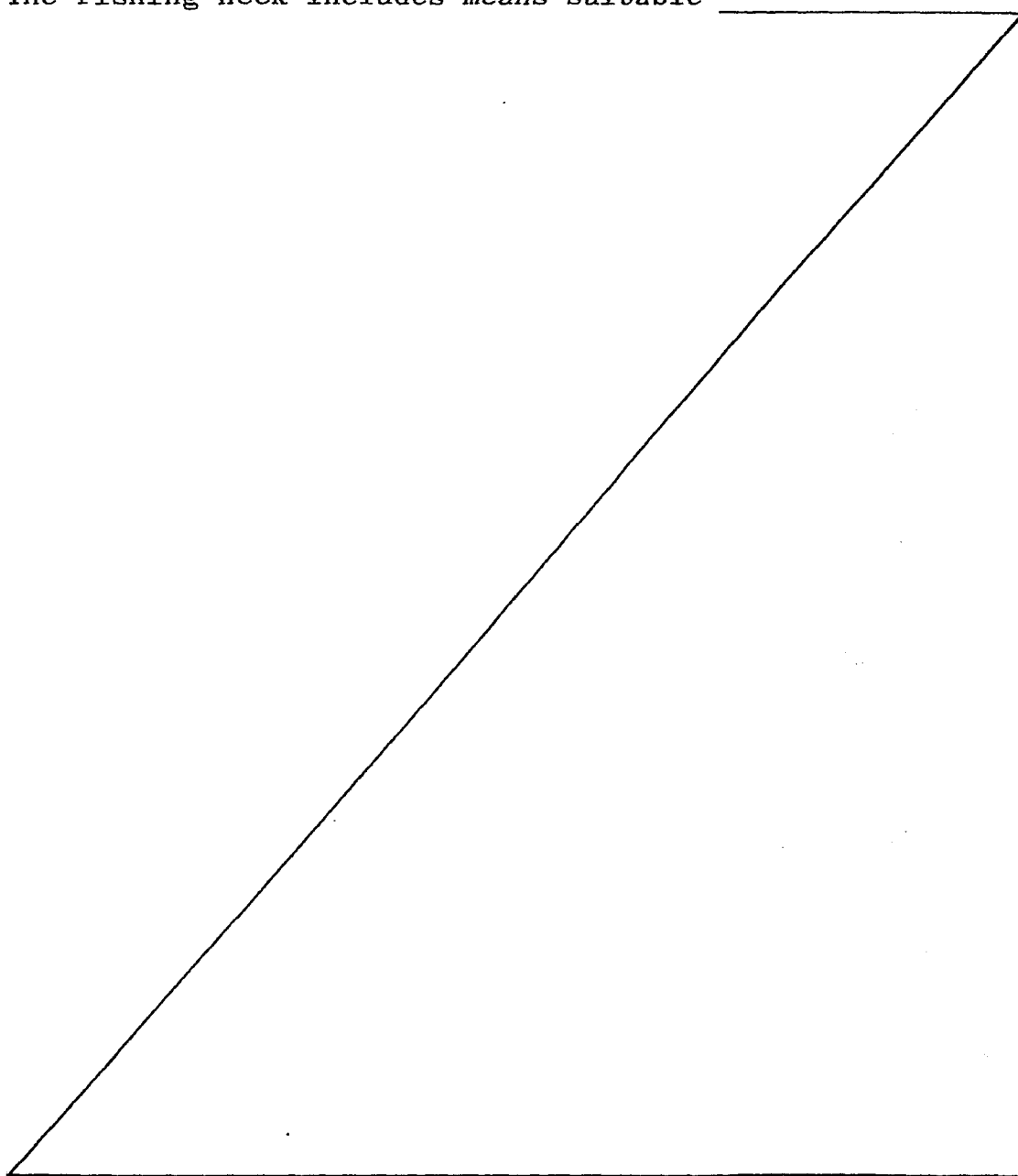
In order that the invention may be more fully understood, reference is made to the accompanying drawings, wherein:

FIGURE 1 is a sectional view through one
5 embodiment of tool constructed in accordance with the present invention; and

FIGURE 2 depicts a pipe string stuck in an open borehole at a specified borehole depth, and shows adjacent to that pipe string a base log, a recording
10 showing several magnetic marks in the pipe string, and a third log showing the change in the intensity of the magnetic marks as a result of stress on the pipe.

Referring to Figure 1 of the drawings, a free point indicator tool 10 of the present invention is
15 shown suspended in a pipe string 12. The pipe string 12 has pipe joints threaded together with couplings 14 to assemble them into a string of substantial length. We assume, for purposes of this description, that it is a drill string that is several thousand feet (1 foot
20 equals 0.3 m) in length and which is formed with many hundred of joints of pipe. The pipe string 12 is located in an open borehole which has an annular wall 16. The borehole is larger than the pipe 12 because it is drilled by a drill bit which is larger than the pipe 12.
25 In ordinary circumstances, the well borehole 16 is more or less circular and will maintain structural integrity so that the pipe string can be positioned in the borehole. As will be understood, the apparatus of the present invention works not only in the circumstances just
30 described but also in cased holes, production tubing strings located inside casings, and in other circumstances, in which a pipe string may become stuck at a depth not known at the surface. The apparatus and method are directed toward determining the location of sticking
35 so that the free point can be determined.

The tool 10 includes a fluid tight housing or body member 18 which is sized for passage in a well borehole and is preferably formed of a non-magnetic material. Composite plastics and fiberglass materials
5 can be used, as can aluminium, brass and stainless steel for example. The housing or body member 18 encloses various components positioned therein. The body member 18 terminates at a fishing neck 20 at the upper end. The fishing neck includes means suitable



for connecting with a conventional armored well logging cable 22. The logging cable 22 has at least one inner conductor. Two conductors are shown (24 and 26) in the preferred embodiment. The conductors
5 24 and 26 can communicate signals to and from the surface.

At the surface, the logging cable 22 passes over a sheave wheel 28. The cable 22 is supplied from a drum 30 which spools the cable in or out as
10 required. The cable conductor 24 is connected to a suitable amplifier and then through a switch 32 to a recorder 34. The conductor 26 is connected through a switch 36 and to a storage capacitor 38. A charge is placed on the storage capacitor 38 from a
15 suitable D.C. power supply 40. The recorder 34 is electrically or mechanically coupled to the sheave 28 by depth measuring means indicated by a dotted line 42. This device measures the rotation of the sheave 28 and thereby measures the depth of the tool
20 10 in the pipe string. The depth measurement signal is coupled to the recorder 34 so that the signal output from the downhole tool 10 can be placed on the storage medium as a function of depth by the recorder 34. The sheave 28 can be connected
25 through a means denoted by dotted line 44 to the

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switch 36 to periodically trigger that switch. This will be described in more detail hereinafter.

In the body member 18 the numeral 24 identifies the conductor which is connected to a first or
5 detector coil 48. There is also a second or marking coil 50. The coil 50 is wound on a suitable ferro-magnetic core 52. The number of turns in the coil and the gauge of the wire in the coil are optimized to produce maximum ampere turns for marking. The
10 storage capacitor 38 furnishes a D.C. current pulse of up to several amperes peak current flow which is conducted via diode 56 to the coil 50. This peak current is conducted through the conductor 26 into the coil 50 and forms a magnetic field external to
15 the non-magnetic body member 18. The magnetic flux of the field is enhanced by the ferromagnetic core 54, and is coupled through the non-magnetic housing 18 into the pipe 12. The pipe 12 is made of ferro-magnetic material such as iron or steel. This
20 process forms a magnetic mark on the pipe 12. The coil 50 is made relatively short to provide a short magnetic mark and core 54 is likewise relatively short. The core 54 can be conveniently formed with a relatively narrow neck for receiving the coil 50
25 wires with enlargements at the ends to direct the magnetic lines of flux into the pipe.

The detector coil 48 which is designed with a maximum number of turns of rather small gauge wire is connected through the conductor 24 via diodes 55 to the surface equipment. Signals induced in the coil 48 by moving it through the magnetic field of the marks induced in the pipe can be quite small. If needed, an amplifier (not shown) can be connected in series with the coil 48 to the conductor 24 in the tool housing 18 so that the detected voltage signal from the coil 48 is preamplified for transmission along the logging cable conductor 24.

In Figure 2 well logs obtained by use of the downhole equipment just described and the recorder 34 are illustrated relative to a stuck string of pipe. The drill string has been stuck at a specified depth. This is exemplified in Fig. 2 where the borehole 16 is shown to have collapsed at 56, thereby trapping the drilling string 12 and sticking the drill pipe.

The log 72 of Figure 2 is the recording obtained by moving the tool 10 along the pipe string 12 while using the coil 48 to detect magnetic anomalies or marks. The log 72 is

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made before any magnetic marks are placed on the pipe string. The single magnetic mark shown in the log 72 corresponds to the collar 58 and hence will be given the same reference numeral and is shown at the same relative borehole depth. This is a magnetic anomaly which is caused by the increased thickness of the wall of the pipe string. The coupling 58 is an enlargement in the pipe string which creates an anomaly or irregularity in the uniform magnetic field of the earth as captured in the ferromagnetic pipe. The downhole tool 10 of this invention is then lowered into the region of the stuck pipe at 56 and a number of magnetic marks are placed on the drill pipe in the manner previously described by pulsing the coil 50 with large amplitude D.C. pulses from storage capacitor 38.

The marking coil 50 in conjunction with the storage capacitor 38 is used to place the magnetic marks 60-70 on the ferrous pipe material. The marks are spaced from one another by a predetermined longitudinal distance. This depends on the frequency with which the switch 36 is tripped and the logging speed. The magnetic marks can be conveniently placed as close as two to three feet (0.6 to 0.9m) apart or they can be made further apart if desired.

The log 74 is made
over the same span of pipe after the magnetic marks
have been placed on the pipe. To this end, the
peaks 60-70 of approximately constant amplitude are
5 included and correspond in depth to the location of
magnetic marks made along the pipe by pulsing of the
coil 50 and the second being caused by magnetic
anomalies at the pipe couplings. At this juncture,
observation of the log 74 shows several magnetic
10 marks but it does not yet indicate the depth of the
free point.

A third log 76 is obtained after the pipe has
been stressed. The pipe is stressed either by
pulling or lifting on the pipe string with the draw
15 works or by applying torque through the rotary
table, or both. The resultant strain induced in the
pipe attenuates the magnetic marks on the pipe
between the surface and the stuck point location at
56 (i.e. the free point). In operation, the pipe is
20 stressed in some manner for a few minutes.
Thereafter, the log 76 is obtained by moving the
downhole instrument 18 past the suspected free
point. The anomaly 58 will show up because it is an
anomaly which persists after straining the pipe.
25 The magnetic mark at 60 is again shown on the log

76, but its amplitude is attenuated. All the magnetic marks above the stuck point location 56 are attenuated or even completely erased. When they are reduced or erased, there is a contrast with the induced voltages obtained from magnetic marks below the free point 56 which are not erased. Thus, the log 76 shows the marks at 60 and 68 to be quite different in amplitude. By comparison of the logs obtained before and after straining of the pipe, the depth of the free point can be determined. The log 76 clearly identifies that the free point occurs between the magnetic marks 66 and 68. Figure 1 shows depth measuring apparatus 28 connected with the recorder 34. With such apparatus and the marks due to pipe joints on the logs, it is possible to calibrate the logs 72, 74 and 76 in terms of depth. It is therefore possible to locate the free point with a high degree of accuracy because the logs are scaled to well depth.

U.S. Patent no. 4440019 describes a tool having a single coil to both mark the pipe with magnetic marks, and to detect the marks so made. However, the use of two separate coils is significantly better than use of a single coil system since the latter is inevitably a compromise rather than an optimum coil array for either marking or detecting marks on the pipe. This is the case because the requirements for marking include optimizing ampere turns while the requirement for detecting marks requires optimizing turns and cross sectional area of a coil. Therefore to design one coil to do both requires a compromise between these two aspects of the coil.

CLAIMS:

1. Free point apparatus for determining the depth of the stuck or free location in a string of pipe in a well borehole, comprising:
 - (a) a cable supported tool (10) adapted to be lowered
5 into a well borehole;
 - (b) first electromagnetic coil marking means (50) carried by said tool for forming a magnetic field acting on the stuck string of pipe in the well borehole; and
 - 10 (c) second electromagnetic coil detector means (48) carried by said tool for detecting residual magnetic fields on the string of pipe as a function of depth in the well borehole.
- 15 2. Apparatus according to claim 1, wherein said tool incorporates a ferromagnetic core (52) supporting a first coil comprising part of said first electromagnetic coil marking means.
- 20 3. Apparatus according to claim 1, wherein said tool incorporates a ferromagnetic core (52) supporting a second coil comprising part of said second electromagnetic coil detector means.
- 25 4. Apparatus according to claim 3, wherein said second electromagnetic coil detector means includes amplifier means connected to said second coil for forming an output signal indicative of a signal magnetically induced in said coil.
- 30 5. Apparatus according to claim 1 to 4, wherein said tool includes a housing member (18) for said coils comprising a non-magnetic material.

6. Apparatus according to any of claims 1 to 5, including means (42) for measuring the depth of said tool in a borehole; and recorder means (34) connected to said depth measuring means and said detector means
5 for recording the intensity of magnetic fields on the stuck string of pipe as a function of depth in the well borehole.
7. Apparatus according to claim 6, including switch
10 means (36) connected to said recorder means and operated to provide signals from said detector means thereto in a controlled and timed relationship.
8. Apparatus according to any of claims 1 to 7,
15 including capacitor means (38) for accumulating a current charge thereon, switch means (36) connected to said storage capacitor, and conductor means (26) extending from said switch means to said electromagnetic coil marking means for delivery of a current pulse thereto
20 for forming a magnetic field acting on a stuck string of pipe.
9. Apparatus according to claim 8, including means operative dependent on the depth of the wireline
25 supported tool in the well borehole, to place spaced magnetic marks along the stuck string of pipe.
10. Apparatus for providing a free point indication is a stuck string of pipe, comprising:
30 (a) a running tool (10);
(b) surface located recording means (34);
(c) pipe marking means (50) carried by said running tool for forming magnetic marks on the stuck string of pipe; and
35 (d) detector means (48) carried by said running tool

to detect an induced voltage when said detector means moves through the field of the magnetic marks on the stuck string of pipe.

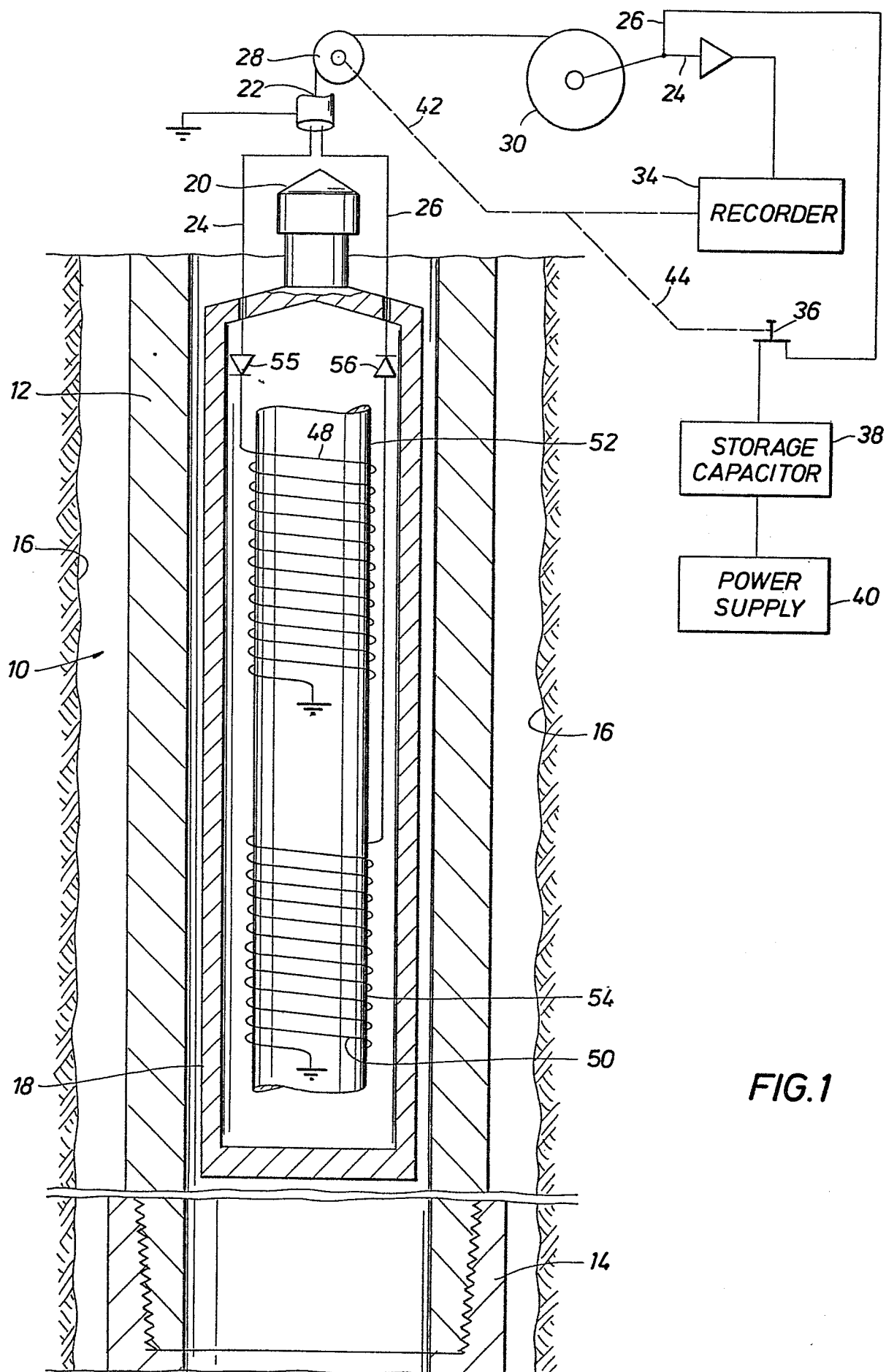


FIG. 1

FIG. 2

