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(54) Method for controlling a drilling operation.

(57) A method for drilling a borehole with a rotating bit connected to another downhole component includes generating a load signal which indicates the mechanical loading placed on the downhole drilling components as a quantified indication of drilling roughness and deriving therefrom an indication of the loading history experienced by the components. The drilling process is then performed in accordance with the drilling roughness or the loading history and appropriate preventive measures are enabled in a timely manner so as to improve the efficiency of the drilling operation or to avoid mechanical failure of the downhole component.

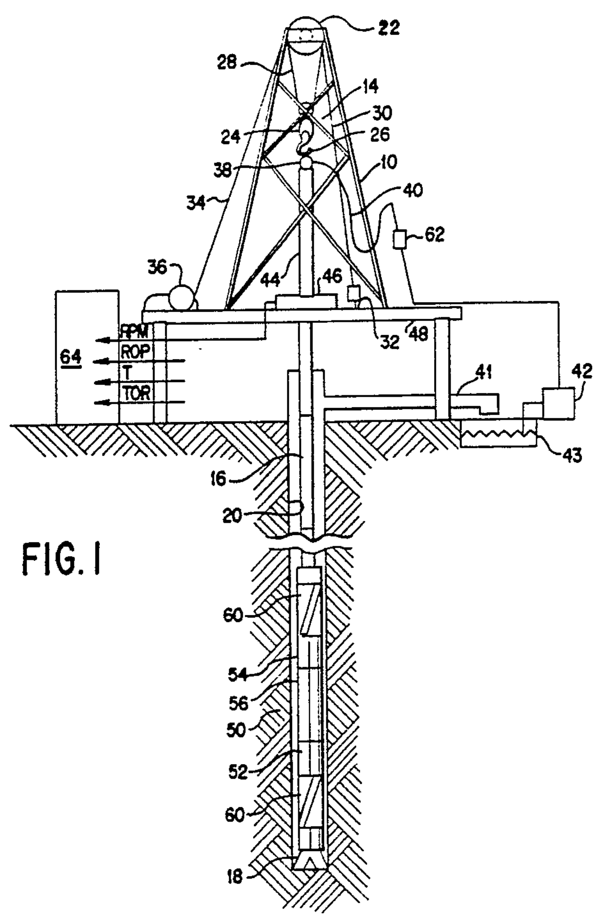

FIG. I

EP 0 336 490 A1

METHOD FOR CONTROLLING A DRILLING OPERATION

It is known that drilling tools all too frequently experience mechanical failures which interfere with the efficient performance of the drilling job. For example. major interruption to the drilling process may be occasioned in the event the drill pipe or other downhole component suffers a mechanical failure to leave part or all of the bottom hole assembly in the bottom of the hole. When this occurs, an expensive and time consuming "fishing" operation is conducted to try to retrieve the lost part. Unfortunately, not all fishing operations successfully conclude with the retrieval of the "fish" which would permit continuation of drilling. When the fishing is unsuccessful , typically the borehole has to be cemented up to a level above the lost "fish" and a sidetrack drilling operation has to be performed in order to avoid the blocked portion of the borehole. Fishing and sidetracking may cost days if not weeks of lost time.

Another type of interruption to the drilling process may occur with the downhole failure of an electronic circuit or some other component in a measurement while drilling tool. Failures of this nature may reduce the effectiveness of the drilling process and may require a shorter interruption while the drill string is tripped out of the hole and the malfunctioning component or tool replaced.

A third type of interruption to the drilling process may occur with the premature wearing of a drill bit or a directional control tool such as a bent housing or stabilizer. It is therefore an object of the current invention to provide quantified information regarding the accumulated load applied to a drilling component in order to provide the basis of an informed decision about when to replace a component or when to perform preventive maintenance.

In addition to the type of failures notes above which reduce the efficiency of the drilling process by occasioning drilling interruptions, it is also possible for the drilling process to be performed without failures but at a less than optimal efficiency. A large variety of different types of drilling bits are currently available to choose from: each designed to function most efficiently under a specific set of circumstances. If the design of a particular bit produces unnecessary vibrations, the drill bit may "skip" or chatter during drilling without permitting its teeth to adequately engage the formation being drilled and its effectiveness is seriously reduced. Detection of conditions in which the bit is functioning in a manner not intended by its designers would permit the driller to either change the drilling conditions to optimize the extraction of formation material or to change the bit by making a bit trip.

The above described interferences are a nuisance at best and may be extremely time consuming, costly and/or dangerous at their worst. While material defects or workmanship are occasionally the cause for failures, many, if not most of the failures are caused by accumulated fatigue of the materials. Corrective measures which may possibly prevent such failures lie in two areas: detecting and avoiding "rough" drilling conditions and accumulating a measure of the total potentially damaging loads to which a drilling component has been exposed.

In view of the fact that the bottom of a borehold is largely unavailable for direct observation, it is not surprising that the design of the best Bottom Hole Assembly (BHA) and the selection of the appropriate bit depends heavily on previous empirical observation in offset boreholes in the same field or in boreholes drilled under similar conditions in similar formations in other fields. It is equally not surprising that the BHA design used in a particular job is sometimes not optimally suited for either the drilling conditions as they actually develop or the rock formations actually encountered. It is therefore an object of the present invention to provide a system and method for providing quantified information on the "roughness" of the drilling operation in order to better enable the drilling operator to determine whether the design of the BHA is satisfactory for the conditions and formations encountered.

In the past, it has been known to perform preventive maintenance on the components involved in the drilling process on a time schedule determined by the total number of hours that a drilling component has spent working in drilling the hole. Another known measure for scheduling preventive maintenance has been the total operating time of the surface pumps.

Despite the best and well intentioned efforts of the personnel involved, mechanical failures have not been eliminated by the practice of preventive maintenance scheduled according to time-in-use. It therefore is desirable to have a more reliable planning system for scheduling preventive maintenance so as to "catch" the failure before it actually occurs.

Thus, it is proposed to avoid the abuse of the downhole equipment by generating and monitoring an appropriate, realtime measurement of the "roughness" of the drilling conditions. Detection of such a measure of "roughness" may enable the selection of procedures that optimize the drilling process with the equipment in use or the selection and utilization of optimal downhole equipment. Similarly, it is proposed to minimize fatigue and to perform timely preventive maintenance by monitoring such a roughness measurement and generating an indication of loading history for a particular downhole component.

A variety of prior attempts have been made to provide information descriptive of the drilling process. U.S. Patent 4,285,236 describes a system for the coninuous monitoring of both rotary torque and RPM of the drill string. U.S. Patent 4,250,758 describes a system which includes a torque meter that measures dynamic torque while drilling. This system averages the time period of individual oscillations in the torque for a fixed number of oscillations and indicates the lenght of the average time in order to better enable determination of the probable cause of the oscillations. U.S. Reissue Patent 28,436 describes a system for determining the actual failure of a downhole drilling bit by monitoring deviations from the expected characteristic oscillations in the torque of the drill string.

U.S. Patent 3,520,375 proposes monitoring a variety of parameters such as RPM, and the stresses and accelerations to which the drill string is subjected accompanied by a comparison to a reference so as to give an indication of the mechanical properties of the rock being penetrated and so as to enable the selection of more suitable drilling parameters. Additionally, an article appearing in the Jan. 6, 1968 issue of the Oil and Gas Journal entitled "New Drilling-research Tool Shows What Happens Down Hole" describes a down hole MWD tool which was designed to measure such things as torque, weight on bit, axial and lateral accelerations, and bending moment. This article makes brief mention of the advantages to be derived from this type of information including the possible use of the data by drilling engineers and equipment designers in making design decisions regarding bit loads, pipe fatigue and failure and down-hole tool operations.

A method has been developed for conducting drilling operations with a plurality of downhole components including a bit, a drill pipe and a bottom hole assembly which may include a downhole motor, a bent sub, one or more stabilizers, roller reamers, measurement while drilling tools and the like. In order to prevent the failure of such a component in the borehole while drilling, it is proposed that a measure be made of the mechanical load experienced per foot by the downhole components from which is generated an indication of the loading history experienced over time by the downhole components. One parameter from which mechanical load may be determined is the uphole or downhole torque: specifically, the number of times a measure of torque exceeds a predetermined threshold related to the specific tool design specifications. The indication of loading history is then utilized in determinations of when particular components must be replaced or maintained and/or in the determination of subsequent drilling practices such as the control of rate of penetration (ROP) through variation of application of weight on bit and/or rate of turning the drill string (ROT).

Figure 1 is an illustration of an MWD apparatus in a drill string having a drill bit while drilling a borehole.

Figure 2 is a block diagram of the interpretation functions performed on the drilling parameters generated from the apparatus of figure 1.

Figure 3 illustrates a plurality of "logs" produced in accordance with the method of the present invention.

Referring initially to figure 1, there is shown a typical rotary derrick comprising a mast 10 standing on the ground 12 and equipped with lifting gear 14, on which is suspended a drill string 16 formed from pipes joined end to end and carrying at its lower end a drill bit 18 for drilling a well 20 in subsurface formations 50. Lifting gear 14 comprises a crown block 22, whose spindle is fixed to the top of the mast 10, a vertically mobile travelling block 24, to which is attached a hook 26, a cable 28 passing over blocks 22 and 24 and forming, as from the crown block 22, on one side an inactive portion 30 anchored to a fixed point 32 and on the other side an active portion 34 wound on to the drum of a winch 36.

The drill string 16 can be suspended on hook 26 via an injection head 38 connected by a flexible hose 40 to a mud pump 42, which makes it possible to inject into the well 20, via hollow pipes of string 16, drilling mud from a mud pit 43, which can also receive excess mud from the well 20 via bell nipple 39 and flow return line 41. By operation of the lifting gear 14 by means of winch 36, it is possible to raise the drill string 16, its pipes being successively withdrawn from well 20 and unscrewed so as to extract the drill bit 18, or to lower the drill string 16, following the successive rescrewing of the pipes forming it, in order to return the drill bit to the bottom of the well. These pipe assembly and disassembly operations make it possible to momentarily unhook the drill string 16 from the lifting gear 14. Drill string 16 is then supported by wedging using wedges or slips in a conical recess of a rotary table 46 mounted on a platform 48 and which is traversed by the drill string. During drilling periods, the drill string 16 is rotated by means of the rotating table 46 via a square pipe or "kelly" 44 mounted at its upper end.

At the bottom end of the drill string, there are shown a plurality of downhole components, including a number of heavy drill collars 54 that make up a bottom hole assembly (BHA) 52. Typically included in the bottom hole assembly immediately above the bit 18 is a full gauge stabilizer 60 which provides lateral stability to the bit and the BHA. A sensor apparatus 56 or MWD is sometimes added to the BHA for the detection of a variety of downhole parameters relating to the drilling process and or to the properties of the formation 50 being drilled. Typical of the measurements made by the MWD are downhole weight on bit (DWOB), downhole torque (DTOR), gamma ray, electrical resistivity and direction and inclination of the borehole.

The DWOB and DTOR transducer may be constructed in accordance with the invention described in U.S. Patent 4,359,898 to Tanguy et al., which is incorporated herein by reference. The outputs of the MWD 56 are fed to a transmitter in the MWD portion of the BHA, as is, by now, well known in the industry, for generating modulated acoustic signals that are modulated in accordance with the MWD measurements. The signal is detected at the surface by a receiving pressure transducer 62 and processed by a processing means 64 to provide recordable data representative of the downhole measurements. Although an acoustic data transmission system is mentioned herein, other types of telemetry systems, of course, may be employed, provided they are capable of transmitting an intelligible signal from downhole to the surface during the drilling operation.

As is known, the BHA may comprise a large number of different components arranged in a variety of different manners in order to produce a variety of different behaviors. For example, one objective to be achieved by the proper design of the BHA is the directional control of the course of the borehole. In furtherance of this objective, the BHA may include a downhole drilling motor with or without a bent housing, a bent sub, full gauge or undergauge stabilizers and reamers etc. Additionally, a large variety of drilling bits are available for selection according to the expected formation and to the type of well to be drilled.

Reference is now made to Figure 2 for a detailed representation of a preferred embodiment of the present invention. Figure 2 illustrates the processing functions performed within the surface processing means 64. While processing means 64 is illustrated as being at the surface, it should be understood that where a downhole value of torque is available from an MWD tool in the BHA, at least a portion of the processing of the data will preferably be performed downhole in the BHA by a microprocessor before transmission of the data to the surface. In this manner, signal compression may be achieved in order to comply with the rather severe telemetry data transmission rate limitations inherent in a typical MWD telemetry system such as a drilling mud pressure modulation system. Acquiring down hole values of torque for the purposes of this invention is preferable to surface acquisition, since friction effects between the bit and the surface frequently attenuate the torsional shocks generated downhole as they propagate up the drill string to the surface.

While a continuous determination of torque (either surface or downhole) may be available for example by monitoring the current of the motor driving the rotary table 46, it is frequently not practicable to continually record each and every value of torque during the drilling operation. Therefore, in response to a torque signal, processing means 64, for each foot drilled, will typically convert the data flow into a statistical representation of the data such as an average value of torque (ATOR) and the standard deviation (TSIG) of torque from that average value. Thus, formulation of the present invention in terms of the stored statistical values enables not only real time generation of valuable information but also permits post drilling analysis.

Accordingly, processor 64, as seen in figure 2, in response to a measurement of torque (TOR) and assuming Gaussian statistics, generates the statistical quantities of TSIG and ATOR at 66 and 68 respectively. These values are not only stored by the processor but are subsequently used through statistical analysis to determine the percent of the time that the torque of the drilling system has statistically exceeded a predetermined value or threshold (TREF). This is accomplished at 70 where the difference between the threshold (TREF) and the average value of torque (ATOR) is divided into the standard deviation value (TSIG). Calculation of this ratio, which is an indication of the loading placed on the downhole components of the drill string is followed at 72 by a conversion of the percent of time that torque exceeds the reference setpoint (TREF) into the number of times (or cycles) that the threshold is exceeded per foot drilled (CYC). This conversion is obtained by multiplying the ratio of block 70 by the ratio of ROT (rate of turning) to twice the rate of penetration (ROP) of the drill string.

While it has been assumed that the data representative of the torque placed on the drill string follows Gaussian statistics, it may be determined from actual experience that the distribution of the data is other than Gaussian. In this event, a suitable transform (for example, taking the logarithm of the data) may be applied in a preprocessing step to obtain a Gaussian distribution. Alternatively, if the data falls into a known category for which a body of statistical mathematical analysis exists, the raw data may be treated accordingly.

The preferred embodiment is described herein to include analysis of torque data that either exhibit

Gaussian statistical behavior or which can be made to exhibit Gaussian statistical behavior through an appropriate preprocessing transform. The analysis is performed to determine an indication of the number of occurances that the selected parameter (torque) exceeds a predetermined threshold. For example, the stalling torque of the rotary table may be used as a threshold in order to generate a mechanical load signal indicative of drilling roughness and a loading history signal. The invention is broadly enough conceived to include parameters other than torque that may be useful in characterizing mechanical load placed on the drill string, such as vibrations, accelerations, string rotation speed (RPM) or pump pressure. While a statistical technique is described, the invention is also broad enough to include the direct comparison of the monitored parameter (torque or other value indicative of load) with a predetermined threshold with a count made of those events which exceed the threshold. Another variation within the scope of the invention is to generate a load signal which varies not only as a function of the number of times that the threshold is exceeded but also as a function of a measure of the magnitude by which the threshold is exceeded. In this manner, the greater tendancy for large excusions above the threshold to produce damage (fatigue) than minor excusions above the threshold can be taken into account. The threshold itself may be selected, either from mechanical engineering fatigue analysis theory or from empirical observation as that value for which excusions above the threshold will significantly contribute to a shortened mechanical lifetime.

Graphical display of the value of CYC in the form of a depth varying log produces a useful quantitative indication of the "roughness" of the drilling process. When available in real time, this log may enable the driller to immediately react to the "roughness" of the drilling operation and to modify his drilling practices in order to minimize the "roughness". Such feedback to the drilling process may enable the avoidance of downhole failure of the components of the BHA, thereby significantly improving the drilling operation.

While, in many instances, reduction of the "roughness" parameter CYC will require reduction of rate of penetration by changing RPM or weight on bit, it must be realized that avoidance of a downhole failure will not only be beneficial in the long run but also the availability of an indication of "drilling roughness" will make available the opportunity to optimize rate of penetration when drilling is shown to be smooth. That is, where the "roughness" log shows smooth drilling (i.e., few occurrences of torsional shocks exceeding the predetermined threshold), the driller then may elect to increase weight on bit or rpm (or change bits) in order to increase rate of penetration so long as the "roughness" remains acceptable. In this manner, the driller may be able to optimize his rate of penetration by varying weight on bit or RPM without increasing the risk of causing a downhole failure.

Figure 3 shows an example of a log of CYC at 82. Figure 3 also shows a log of TCYC at 84 which stands for the sum or accumulation over depth of the torsional loading placed on the drill string. This loading history signal, calculated at 74 in Fig. 2, is useful to the driller as a quantitative indication of the total abuse to which the drill string (bit) has been subjected. Experience using this loading history will enable the driller to evaluate the expected lifetime of the drilling components so that he will be able to use the equipment up to the end of its useful life without incurring downhole failures of the equipment which would be probable without knowledge of the loading history.

The loading history TCYC as illustrated in figure 3 is returned to zero after the replacement of each bit in order to track bit loading through each of their useful lives. Alternatively or additionally, it may be desirable, to keep a running value from bit run to bit run so as to generate an accumulated signal for other components of the drill string or BHA. Indeed, it may be desirable to keep a running loading history over the life of individual components (stabilizers or drill pipes for example) even though a particular component may participate in the drilling of many wells.

In this same spirit, it is proposed by the present invention to generate an indication of equivalent operating time or "equivalent shock time" (shown at 86 of figure 3) for individual down hole components. Equivalent shock time (EQST) is a time index calculated from the loading history of the component. Simply conceptualized, a component that has experienced benign drilling conditions and a component used for the same period of time but under abusive conditions, will have different life expectancies. "Equivalent Shock Time" is therefore a synthetic period of time calculated to express the time that a component has been used in drilling while also taking into consideration the severity of the drilling conditions and a tool design factor for dynamic loading (FDES). Once, EQST is determined, it may be divided at 78 by the total drilling time (T) to derive a dynamic shock factor (FDYN) which may also be used as an indication of the roughness of the drilling conditions. Utilization of equivalent shock time in establishing maintenance schedules, rather than actual time of use, will permit more effective preventive maintenance programs. EQST may also be used as an indication of component reliability.

Returning, then to figure 2, it can be seen that processor 64 responds at 76 to the determination of the ratio of TSIG divided by (TREF-ATOR) and rate of penetration to calculate values of EQST on a foot by foot bases. As will be noted from the figure, a constant, design factor (FDES), specific to the particular equipment under consideration, may be included in the calculation to more properly tailor EQST to the particular equipment. When summed and divided by the current total drilling time, the parameter (FDYN) or dynamic shock factor is produced at 78. As illustrated, CYC, TCYC, EQST and FDYN are delivered by processor 64 to a printer 80 which generates depth varying logs to which the driller may refer in order to optimize his drilling practices.

In the context of the above description, CYC and EQST are both signals indicative of mechanical loading while TCYC and the summation of EQST over time are signals indicative of loading history. As mentioned, other parameters such as accelerations, vibrations, RPM, and pump pressure may function as signals indicative of mechanical loading and loading history. Additionally, while replacing the bit with a more suitable bit for the drilling conditions, replacing a straight blade stabilizer with a helical stabilizer, replacing a stablizer with a roller reamer, changing the rate of rotation of the drilling components, changing the weight placed on the drilling components, and replacing a drilling component having a high loading history with one having a lower loading history are non-limiting examples of measures that the driller may take to modify the drilling operation, it is also contemplated that determination of a replacement or maintenance schedule in response to mechanical loading which exceeds a threshold are also practices that have an effect on the drilling operation.

Claims

A method for conducting the operation of drilling a borehole with a plurality of downhole components including a bit, comprising the steps of:

a. predetermining a mechanical loading threshold;

b. generating a signal indicative of mechanical loading placed on said downhole components;

c. in response to said threshold and to said loading signal, generating a signal indicative of loading which exceeds said threshold; and

d. in response to said signal indicative of loading which exceeds said threshold, modifying the drilling operation.

2. The method as recited in claim 1 further including the step of generating a signal indicative of the loading history experienced by said downhole component.

3. The method as recited in claim 1 wherein said step of generating a signal indicative of mechanical loading includes the step of determining an indication of torque experienced by said drilling components.

4. The method as recited in claim 2 wherein said step of generating a signal indicative of loading history includes the step of accumulating over time an indication of the number of occurrences for which the loading placed on a downhole component exceeds a predetermined threshold.

5. The method as recited in claim 2 wherein said signal indicative of loading history includes a portion indicative of a previous loading history of a downhole drilling component and a portion indicative of accumulated current loading on said downhole drilling component.

6. The method as recited in claim 2 further including the step of comparing said loading history signal to a lifetime threshold predetermined for said downhole drilling component and taking action in response to the comparison.

7. The method as recited in claim 1 including the steps of monitoring surface torque;
deriving an indication of the standard deviation of the surface torque; and
deriving said loading signal in response to said indication of standard deviation.

8. The method as recited in claim 1 including the steps of monitoring downhole torque;
deriving an indication of the standard deviation of the downhole torque; and
deriving said loading signal in response to said indication of standard deviation.

9. The method as recited in claim 2 wherein said loading signal is indicative of the number of times a measure of torque exceeds a threshold and of the magnitude by which said measure of torque exceeds said threshold.

10. The method as recited in claim 1 wherein said step of modifying the drilling operation includes performing one or more measures selected from the group comprising:
replacing the bit with a bit more suitable for the drilling conditions;
replacing a straight blade stabilizer with a helical stabilizer;
replacing a stabilizer with a roller reamer;
changing the rate of rotation of the drilling components;
changing the weight placed on the drilling components; and

replacing a drilling component having a high loading history with one having a lower loading history.

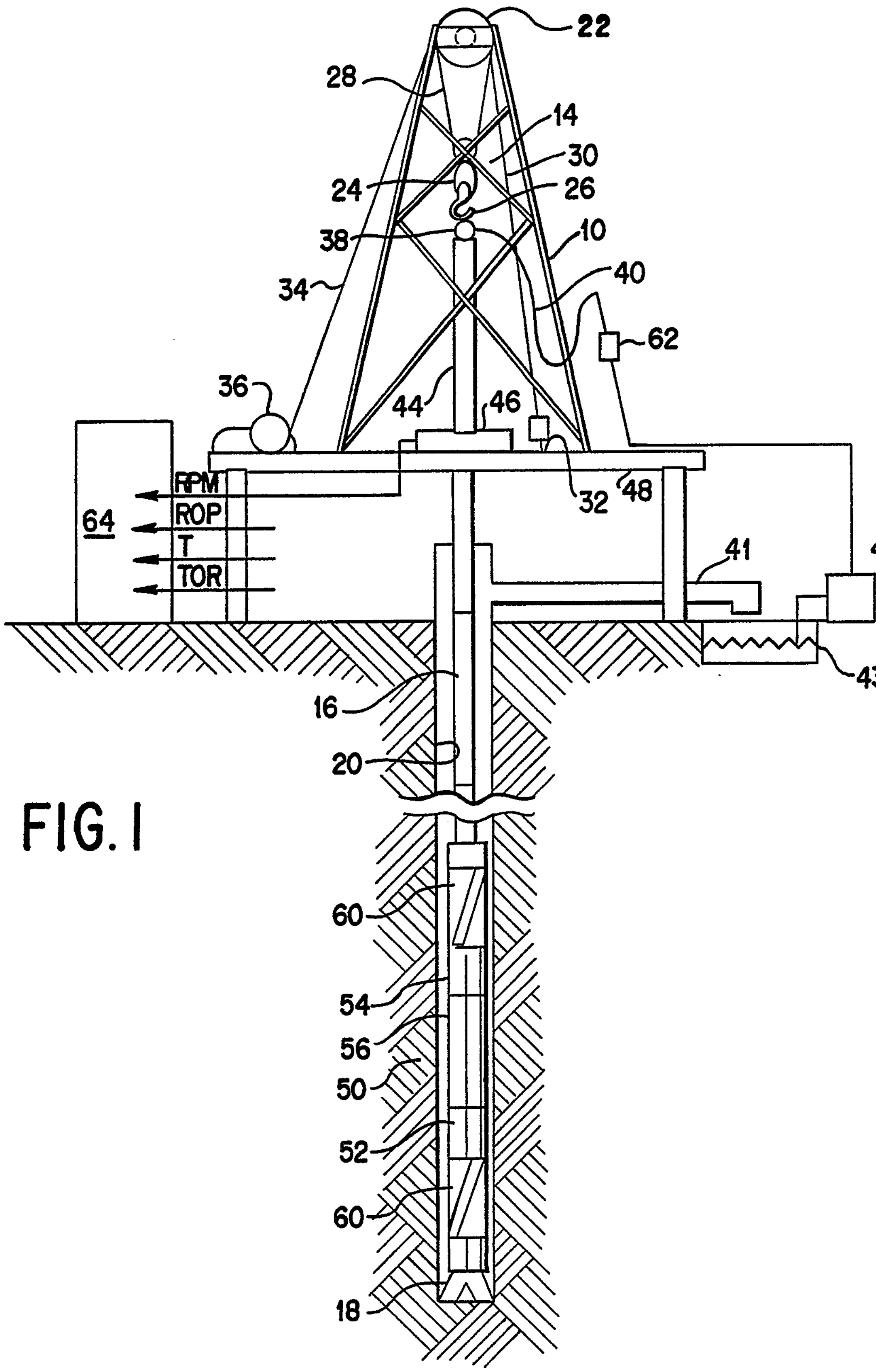
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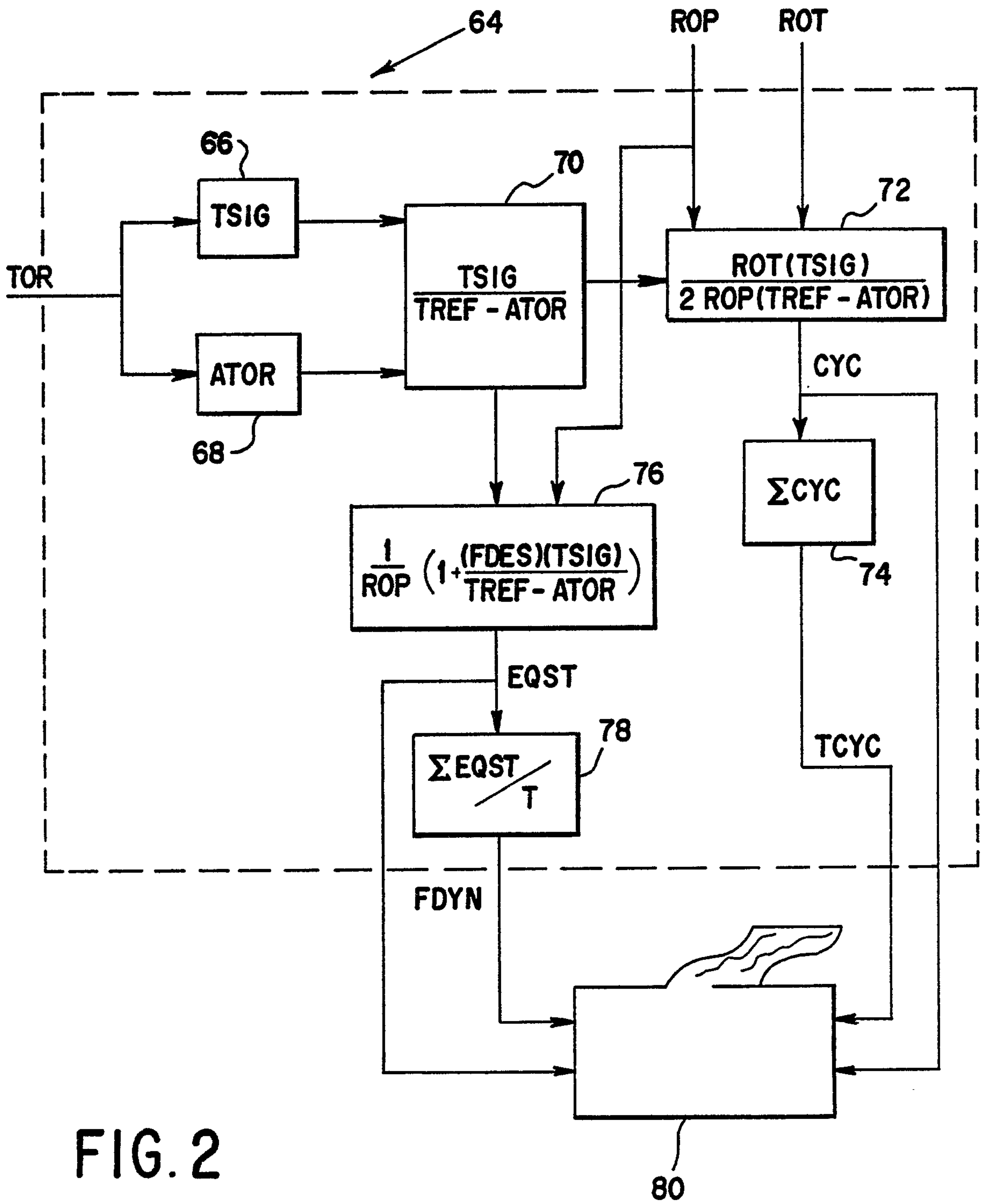
FIG. I


64
ROP
ROT
66
TSIG
70
TSIG
TREF - ATOR
72
ROT(TSIG)
2 ROP(TREF - ATOR)
TOR
ATOR
68
CYC
ΣCYC
74
76
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ROP
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TREF - ATOR)
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ΣEQST
T
TCYC
FDYN
80

FIG. 2

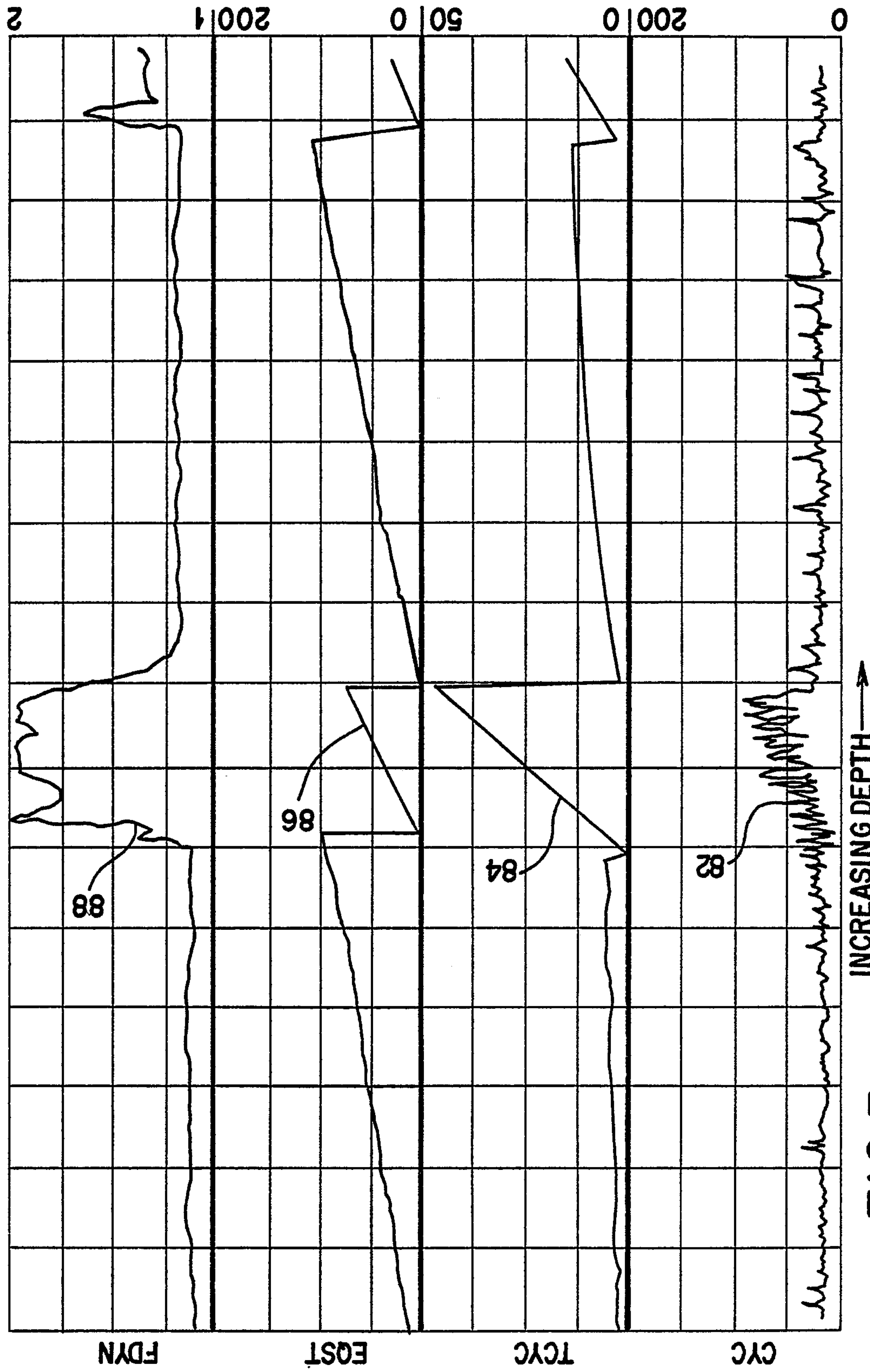
FDYN
EQST
TCYC
CYC
2
200|1
200|0
50|0
200|0
0
82
84
86
88
INCREASING DEPTH

FIG.3

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EUROPEAN SEARCH REPORT

Application Number

EP 89 20 0796

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	FR-A-2 485 616 (NAUCHNO-ISSLEDOVATELSKY) * Claim 1 *	1-6	E 21 B 44/00
Y	---	10	
X	US-A-3 324 717 (BROOKS et al.) * Column 6, lines 17-32 *	1,3,7,8	
Y	---	10	
X	US-A-4 064 749 (PITTMAN et al.) * Claims 1-3 * ---	1-3,6-9	
X	US-A-3 593 807 (KLIMA) * Claim 1 * ---	1,3,7,8	
X	US-A-3 605 919 (BROMELL et al.) * Claim 3 * ---	1,3,7,8	
X	EP-A-0 163 426 (PRAD) * Whole document * ---	1-3,5,6	**TECHNICAL FIELDS SEARCHED (Int. Cl.4)**
D,A	US-E- 28 436 (VITTER et al.) * Whole document * ---	1	E 21 B
D,A	US-A-4 285 236 (CHIEN) * Whole document * ---	1	
D,A	US-A-4 250 758 (PITTS et al.) * Whole document * ---	1	
D,A	US-A-3 520 375 (RAYNAL et al.) * Whole document * --- -/-	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	07-07-1989	SOGNO M.G.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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EUROPEAN SEARCH REPORT

Application Number

EP 89 20 0796

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
D,A	THE OIL AND GAS JOURNAL, 8th January 1968, pages 55-64; F.H. DEILY et al.: "New drilling-research tool shows what happens down hole" * Whole article * -----	1	
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)

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L : document cited for other reasons

& : member of the same patent family, corresponding document

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