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[54] **METHOD AND APPARATUS FOR MONITORING THE WEAR ON A ROTARY DRILL BIT**

[75] Inventors: **Herbert A. Rundell; James B. Davis,**
both of Houston, Tex.

[73] Assignee: **Texaco Inc.,** New York, N.Y.

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[58] Field of Search. **73/151, 151.5, 133;**
175/39

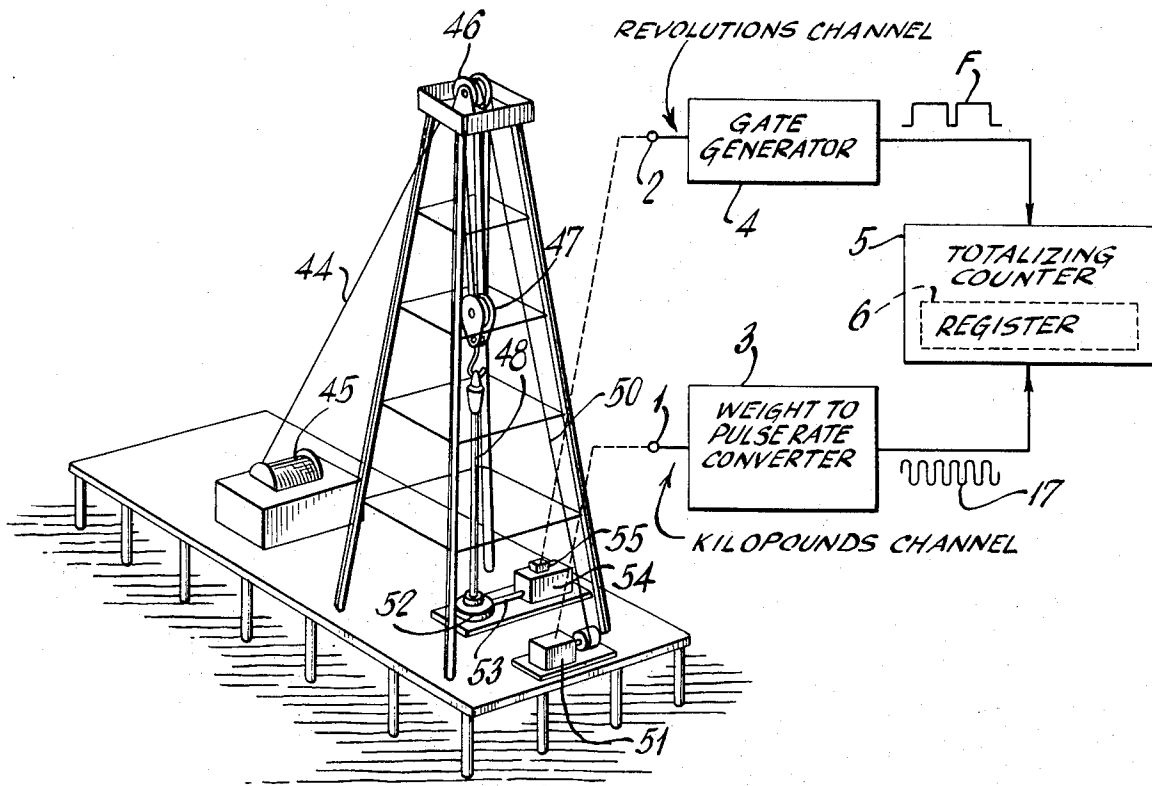
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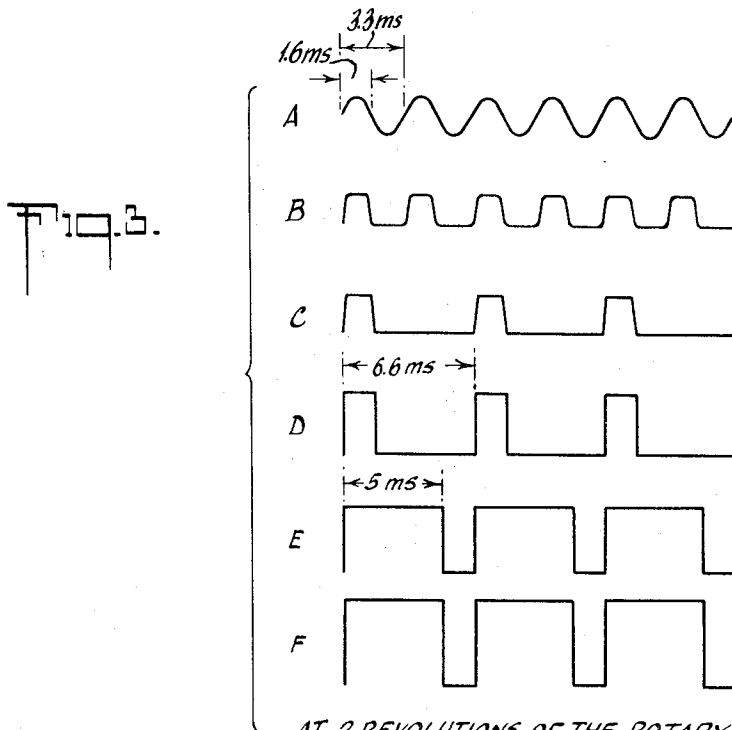
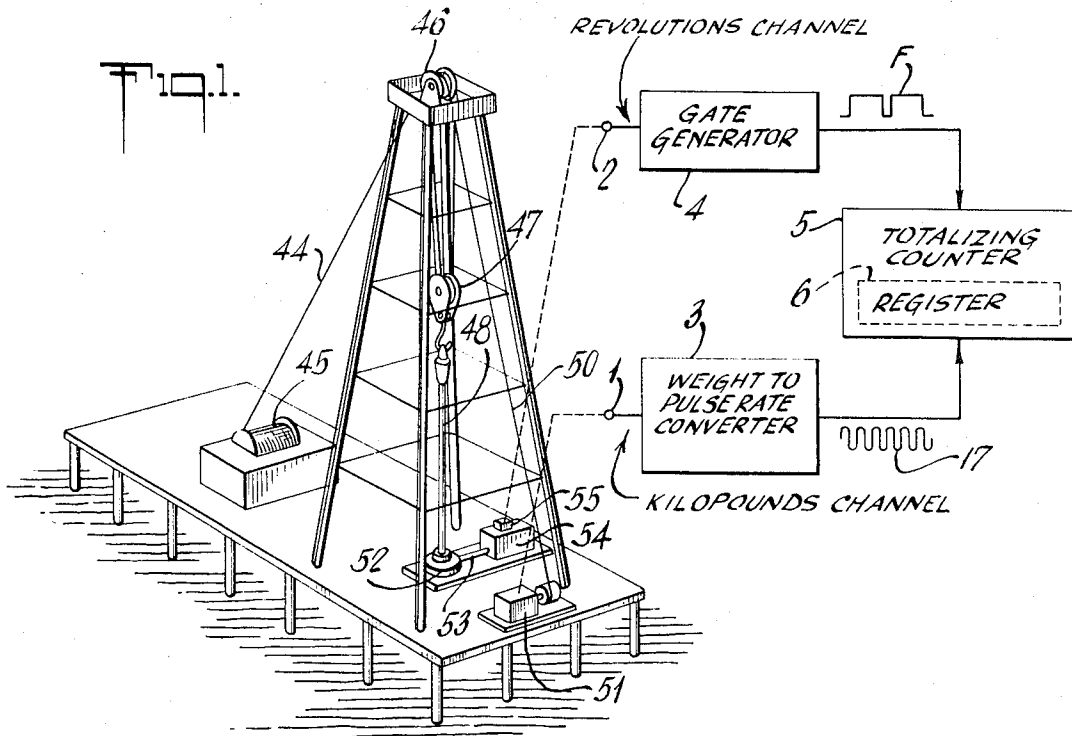
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Primary Examiner—Jerry W. Myracle
Attorney—Thomas H. Whaley et al.

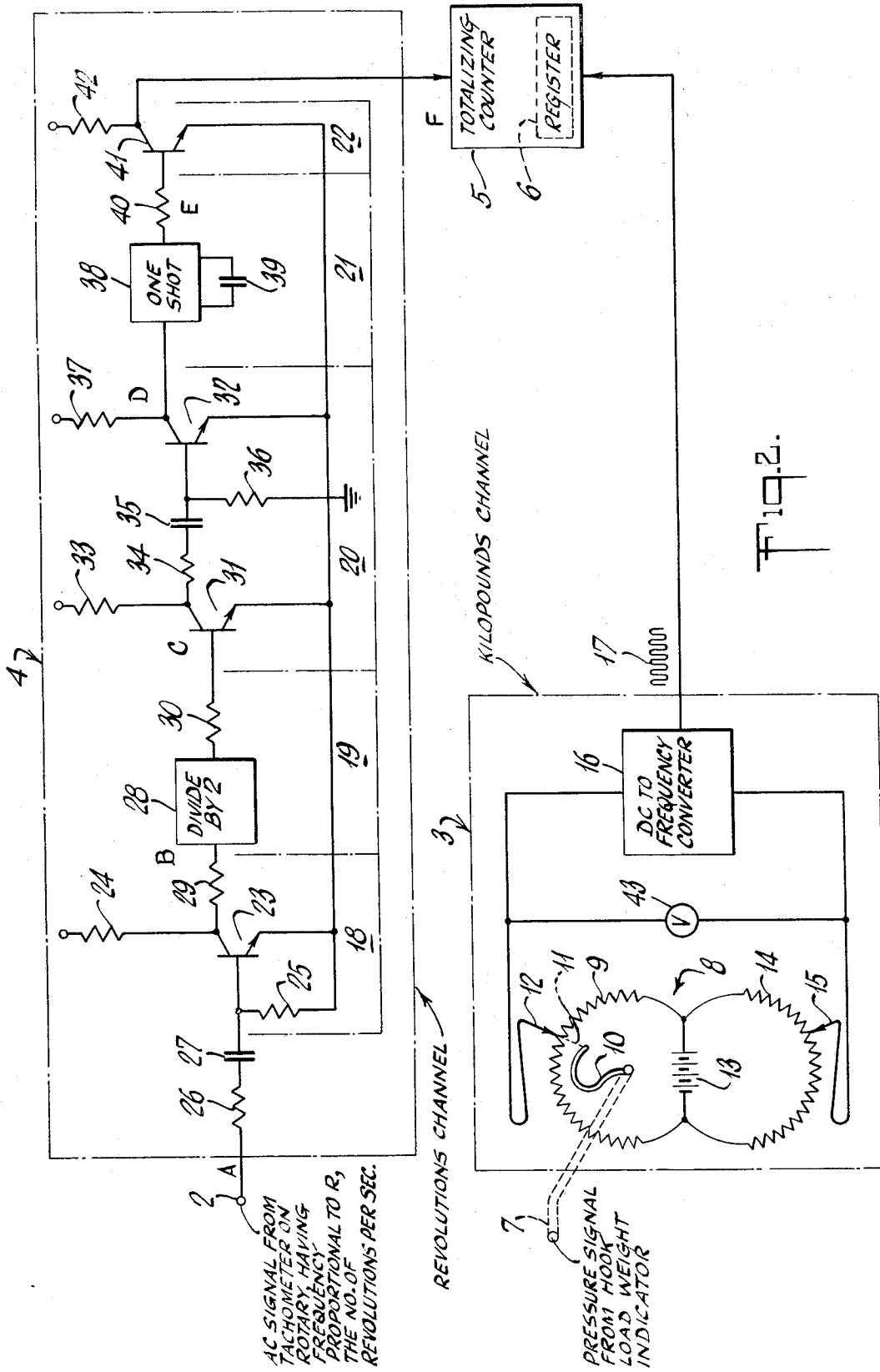
[57] **ABSTRACT**

A method and apparatus for monitoring the wear on a rotary drill bit including means for measuring the revolutions of the drill string and the weight on the bit, and for obtaining the product thereof, such product being a measure of the wear on the bit. A pulse train is generated having a pulse rate proportional to the weight on the bit. Controlled portions of the pulse train are registered in a counter, the portions being proportional in duration to the number of revolutions turned by the bit, with the result that the accumulated count registered provides at any time the integrated product of weight and revolutions, as a measure of bit wear.

9 Claims, 3 Drawing Figures



AT 2 REVOLUTIONS OF THE ROTARY/SEC.
AND 150 ELECTRICAL CYCLES GENERATED
BY THE TACHOMETER EACH REVOLUTION, THERE ARE
300 ELECTRICAL CYCLES/SEC. OR
A PERIOD OF 3.3 ms.



METHOD AND APPARATUS FOR MONITORING THE WEAR ON A ROTARY DRILL BIT

BACKGROUND OF THE INVENTION

In rotary drilling operations, such as drilling for oil, a drill bit is lowered on the end of a drill pipe to the bottom of the borehole. The weight of the whole string of drill pipe, including one or more heavy drill collars just above the bit, is large, usually measured in thousands of pounds, or kilopounds. This weight is sensed on the drilling platform as the hook load on the traveling block of the drilling rig. When the bit is resting or drilling on bottom, some of the total weight of the drill string is borne by the earth formation under the drill bit, while the remainder is still borne by the hook and thus appears as a reduced hook load on the drilling rig. The amount by which the hook load is reduced when the bit is on bottom represents the downward force or thrust of the drill bit upon the earth formation. This difference in hook load is called the weight on the bit, and is measured customarily in kilopounds.

After a drill bit has been in operation for an extended time it becomes worn, with the result that optimum rates of drilling are no longer achieved. Continued operation under these conditions is costly. Moreover, continued use of a worn bit may lead to the failure of the bit, with the possibility of parts of the bit coming loose in the borehole and presenting an obstacle to subsequent drilling. Consequently, it is of interest to the drilling operator to monitor the wear to which a drill bit has been subjected during its use in a borehole, in order to make the most efficient use of the drilling equipment.

The amount of wear on a drill bit may be measured by the product of the weight on the bit, which may be expressed in kilopounds, and the amount of rotary (or angular) movement, in revolutions, that the bit has experienced, or to be more precise, it can be measured by the product of the weight on the bit during a certain time interval and the amount of rotary movement that the bit makes during that same time interval, then determining the same product for a succeeding time interval, and again for a still later time interval, and so on, and then summing all such products over all such time intervals in order to obtain the kilopounds — revolutions product for the entire time that the bit is turning on bottom. The present invention comprises a method and apparatus for continually making measurements at the drilling platform and deriving from these measurements a quantity that is a measure of the wear on the drill bit.

It is recognized that there have been proposed various ways to generate and record analog signals which are indicative of the weight on the bit, the revolutions that the bit has experienced as well as the product of these quantities. However, the present invention provides a superior method and apparatus for accomplishing such objectives in a manner that is particularly well adapted to deriving its inputs from known drilling-rig equipment. In addition, this invention is more accurate than any known prior system. The latter is because of the fact that the present invention provides for taking the sum of incremental products rather than the simple product of any particular value of the weight times the revolutions.

SUMMARY OF THE INVENTION

According to the present invention, a measure of the product of weight and rotary (or angular) movement is obtained as follows. For every increment of preselected magnitude of rotary movement of the drill bit one gate signal of preselected time duration is initiated. At the same time, there is continuously generated a pulse train having a pulse rate proportional to the weight on the bit. The pulse train is continuously introduced into a counter for pulses, said counter being enabled to register such pulses only during the time interval while an external gate signal is being applied to the counter, or in other words, only while such gate signal is maintained at an input to the counter. Each of the aforesaid gate signals of preselected time duration is applied as an external gate signal to the counter, thus enabling the counter to register all pulses which occur within the time duration of each such gate signal. The number of pulses thus registered by the counter during the application of each gate signal is a digital number whose magnitude is a measure, i.e., a digital display, of the product of the weight on the bit and one increment of rotary movement of the bit. Such product is a measure of the wear on the bit during each such increment of rotary movement.

Finally, the total number of pulses registered by the counter during the application of all such gate signals is a digital display of the sum of the products of the weight on the bit and the amount of rotary movement that the bits makes with each such weight on the bit. The drill-bit wear is measured by such sum of the products and, therefore, also by the total number of pulses registered by the counter.

The increments of rotary movement of the drill bit are always taken of the same preselected magnitude, and correspondingly the signals initiated for each such increment are also always of the same preselected time duration. If the pulses of the pulse train that occur during all the successive increments of rotary movement of the bit are counted or totalized, the total will be a digital number proportional to the sum of the products of the weight on the bit and each corresponding increment of rotary movement of the bit. Since the weight on the bit is customarily measured in kilopounds and the rotary movement of the bit is measured in revolutions, the total count so obtained for all operations with a given bit will be proportional to, i.e., will be a digital display of, the summed or integrated product of the weight on the bit and the rotary movement of the bit for all increments of such rotary movement. In other words, the total count will be a digital display of the kilopounds-revolutions to which the bit has been subjected.

It is a principal object of the present invention to provide a method and apparatus for continually monitoring the wear on the drill bit.

It is another object of this invention to provide a method and apparatus for continually making measurements at the surface of the earth and continually deriving from these measurements a quantity that is a measure of the wear on the drill bit, so that the operator will be able to monitor the wear on the bit and to estimate at any time the amount of useful life remaining in the bit.

It is still another object of this invention to provide a method and apparatus for continually making mea-

surements at the surface of the earth and continually deriving from these measurements a digital quantity that is a highly accurate measure of the wear on the drill bit, which digital quantity retains its high accuracy over extended periods of time.

These and other objects, advantages and features of the invention will be more fully set forth below in connection with the best mode contemplated of carrying out the invention as set forth in the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a representation of a drilling rig and, in block-diagram form, the manner in which the method and apparatus of this invention can be tied in with the rig to produce the desired result, namely, a continuously obtained measure of the wear on the drill bit;

FIG. 2 is a more detailed schematic circuit diagram of the portion of FIG. 1 which is represented by block diagram; and

FIG. 3 is a time-sequence diagram of the voltage signals developed in the system of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference to FIG. 1 of the drawings, there is shown a schematic representation, or block diagram, of the system of the invention as it ties in with a drilling rig. Drilling line 44 passes from a draw works 45 over a crown block 46 and traveling block 47. The latter supports the drill stem by means of a top joint of the drill stem, or a kelly 48. The anchored end of the drilling line, or a dead line 50 is at all times under a tension which is proportional to the line-supported weight of the drill stem, i.e., the hook load. Such tension is continually measured by a hook-load weight indicator 51 which is connected to the dead line 50 at the dead-line anchor.

The drill stem is driven in rotation through the action of a rotary table 52 upon kelly 48. The rotary table 52 is driven in rotation by a shaft 53 which, in turn, is driven by a rotary drive engine 54. The rate of rotation is continually measured by an A.C. tachometer 55, which may be an integral part of rotary drive engine 54. Also, a time signal indicating the completion of each preselected and fixed increment of rotary (or angular) movement of the bit is revolutions (usually a fractional value of one revolution) is fed from the tachometer 55 into a "Revolutions Channel" at input terminal 2.

A signal proportional to the number of kilopounds weight supported by the drilling line, i.e., the hook load, is fed from the hook-load weight indicator 51 into a "Kilopounds Channel" at input terminal 1. Then, after appropriate conversion of the kilopounds signal to a pulse train having a pulse rate proportional to the weight on the bit in the "Weight To Pulse Rate Converter" 3, a totalizing counter 5 registers the pulse train during the time of a gate signal. Such gate signal is derived from the time signal, and it is a time gate signal of preselected and fixed time duration which is developed in the "Gate Generator" 4. Consequently, the total number of counts showing at any time on a register 6 is a measure of the total number of kilopounds-revolutions to which the bit has been subjected.

In order to make the register 6 direct reading in kilopounds-revolutions, one can calibrate it either by direct

experimental calibration, or by using the readily found apparatus constants, namely, the ratio of kilopounds-to-pulse rate for converter 3 and the number or fractional number of revolutions per preselected increment of rotary movement between successive time gates for the gate generator 4.

While one skilled in the art might devise other equivalent means, FIG. 2 illustrates in more detail some of the elements disclosed schematically in FIG. 1. In FIG. 2 elements which correspond to elements in FIG. 1 are designated by like reference characters and numbers.

The input to the kilopounds channel is derived in the following manner from the reading of the hook-load weight indicator 51. Such a weight indicator consists of a pressure transformer (not shown) attached to the dead line 50 at the dead-line anchor. Tension on the dead line 50 exercises a transverse force on the pressure transformer which, in turn, develops a corresponding pressure signal in an hydraulic tubing 7 which leads to a transducer 8. Transducer 8 consists of a potentiometer 9 driven by a Bourdon tube 10 and a mechanical movement 11. It acts in such a manner that as the hook load increases, the pressure in tubing 7 increases. Consequently, a moving contact 12 is moved along the potentiometer windings, with the result that the voltage that appears on the lead connected to contact 12 is correspondingly increased. There is a battery 13 which supplies the electromotive force to potentiometer 9. And, connected in parallel with potentiometer 9 and supplied by the same battery 13, there is a second potentiometer 14, which is a duplicate of potentiometer 9. It has a moving contact 15 which is manually adjustable.

The foregoing hook-load weight indicator might be a Type E weight indicator which is manufactured by the Martin-Decker Corporation, Santa Ana, Calif. It is described in their Bulletin P-92.

In operation, contact 15 is set at the same electromotive force value along potentiometer 14 as contact 12 is along potentiometer 9, while the drill bit is off the bottom of the hole. This is done by adjusting contact 15 until there is a null between contacts 12 and 15 while the bit is off the bottom. Then, when the drill bit is resting or drilling on bottom, the pressure in tubing 7 is found to be reduced by an amount representative of the weight on the bit, and contact arm 12 assumes a new position at a lower electromotive force representative of the reduced hook-load weight. The contact arm 15 remains where it was previously set on potentiometer 14. The difference in electromotive force between contacts 12 and 15 on potentiometers 9 and 14, respectively, is thus a D.C. electrical signal representative of the difference in the hook load before and after lowering the bit onto the bottom, i.e., a bias signal representative of the weight on the bit. Consequently, transducer 8 with its potentiometer 9 thus biased by potentiometer 14 is said to be a biased weight transducer.

The D.C. electrical signal so derived is introduced into a conventional D.C. to frequency converter 16 which generates an alternating output 17 having a frequency proportional to the amplitude of the input signal and, thus, proportional to the weight on the bit. This alternating signal 17 is fed into the totalizing counter 5 where every positive (or negative) half-cycle of the alternating signal is counted, provided the gate of counter 5 is open. Opening of the gate so as to enable counter 5 is determined by the signals from the

revolutions channel, as explained below. Register 6 presents the total number of such half-cycles counted. It may be noted that this is the same pulse train which was previously described in connection with FIG. 1.

The input at terminal 2 of the revolutions channel is derived directly from an A.C. tachometer and is an alternating signal having a frequency directly proportional to the frequency of rotation of the rotary table and hence also of the drill bit. Such a signal may be derived advantageously from the windings of a torque meter such as that described in U.S. Pat. No. 3,295,367, wherein, as described in the patent, there are 30 electrical cycles generated per revolution of the rotary drive shaft. For a typical case where there is a gear ratio such that there are five revolutions of the drive shaft for one revolution of the rotary table, there will be 30×5 or 150 electrical cycles generated by the tachometer per revolution of the rotary table.

In this case, if we were to use as the time signal every positive half-cycle of the A.C. electrical signal derived from the tachometer, the preselected and fixed increment of rotary movement so determined would be $1/150$ of one revolution. Thus, referring to FIG. 3, signal A after isolation and skaping in section 18 of the revolutions channel, yields signal B. Signal B is nearly a square pulse as a result of a transistor 23 being driven to saturation.

However, after dividing-by-two in section 19 of the gate generator 4, signal C is obtained, where it will be seen that only every other positive-going pulse of signal B has been passed. It is advantageous, as will be explained below, to use every other positive half-cycle of the A.C. signal, rather than every half-cycle. Therefore, the preselected and fixed increment of rotary movement employed for generating the time gate is $1/75$ of one revolution instead of $1/150$ of one revolution.

With reference to FIG. 2, signal C is pulse-shaped in a section 20 of the gate generator 4, and it yields signal D with its pulse shaped as to both height and width. These pulses D are used to trigger a gating section 21, wherein each input pulse of signal D is caused to initiate a gate pulse of preselected and fixed time duration. In the example illustrated, this is one of the pulses E which each have a duration of 5 milliseconds. Each of these gate pulses terminates after such time duration, and the next gate pulse is not initiated until the arrival of the next triggering pulse of signal D. These gate pulses of signal E are further amplified in a gate-amplifying section 22 to provide gate signals F which have sufficient amplitude to operate totalizing counter 5 while also having the same preselected and fixed time duration as did signal E.

Pulse-shaping section 18 contains N-P-N transistor 23 which is connected in common-emitter circuit configuration. It has its emitter grounded, its collector supplied from a plus 20-volt B-supply through a resistor 24, and its base connected to ground through a resistor 25. Signal A is introduced into this pulse-shaping section 18 through a resistor 26 and a capacitor 27 connected in series between input terminal 2 and the base of transistor 23.

Section 19 contains a divide-by-two operational amplifier 28 which has its input supplied through a resistor 29 from the collector of transistor 23, and its output supplied through a resistor 30 to the input of the pulse-shaping section 20. This divide-by-two amplifier 28 may be an integrated circuit which is wired as a flip-

flop and an AND gate. As will be explained below, the dividing by two is necessary in the particular embodiment of the invention in order to allow a gate time sufficiently long such that at high rotary speeds and light bit loads it will permit the counter 5 to count a statistically significant number of half-cycles of signal 17 (from the D.C. to frequency converter 16). It may be noted that a satisfactory converter might be one such as the Anadex Model DF-110R unit, having 10 to 100 kilohertz full scale, which is manufactured by Anadex Instruments, Inc. of Van Nuys, Calif.

Pulse-shaping section 20 consists of N-P-N transistors 31 and 32, both in common-emitter circuit configuration, having their emitters grounded. The input to section 20, taken through resistor 30 from section 19, is applied to the base of transistor 31, the collector of which is supplied by a plus 3-volt B-supply through a resistor 33. Transistor 32 is coupled to transistor 31 through a resistor 34 which has one end connected to the collector of the transistor 31 and the other end connected to one terminal of a capacitor 35. Capacitor 35, in turn, has its other terminal connected to the base of transistor 32. The base of transistor 32 is also connected through resistor 36 to ground. The collector of transistor 32 is supplied by a plus 3-volt B-supply through a resistor 37.

The output from pulse-shaping section 20 is taken from the collector of transistor 32, and it is direct-coupled to the input of a "one-shot" operational amplifier 38 which is in gating section 21. This operational amplifier 38 is an amplifier which produces an output gate pulse of preselected voltage level and time duration whenever it receives a trigger pulse at its input. Suitable amplifiers for this purpose are commercially available in integrated circuit form.

The time duration of the output gate pulse is determined by a capacitor 39 which is connected to appropriate terminals provided for such purpose on the "one-shot" operational amplifier. Gating section 21 consists of the operational amplifier 38 and a resistor 40.

The output of operational amplifier 38 is connected through the resistor 40 to the input of the gate-amplifying section 22, at the base of a transistor 41. Transistor 41 is connected in common-emitter configuration, with its emitter grounded and its collector supplied from a plus 5-volt B-supply through a resistor 42. The output from gate-amplifying section 22 is taken from the collector of transistor 41 and is fed directly into the totalizing counter 5.

A suitable counter for use as a totalizing counter might be one available commercially which is designated as the Anadex Model CF-604R Preset Scaler Timer. This would be operated in "BATCH" mode, as recommended by the manufacturers, in order to get read-out in the desired engineering units. The indicated counter is made by Anadex Instruments, Inc., Van Nuys, Calif.

In operation, when a new drill bit is placed in use, and while the bit is just off the bottom of the hole, and the mud pumps are running, the operator would zero the biased weight transducer 8 (FIG. 2) by manually setting the sliding contact 15 of potentiometer 14 (in the kilopounds channel) to produce a null between contacts 12 and 15. Such null would be observed by reading a volt-meter 43 which is connected across the input to the converter 16. This null condition assures that

contact 15 is correctly set for applying a voltage level corresponding to zero weight on the bit to the converter 16.

Then, the bit would be lowered to the bottom of the hole, and thereafter, while drilling is under way, contact 12 would automatically and continuously be adjusted to positions on potentiometer 9, having reduced voltages corresponding to lower values of hook load, as already indicated above. Consequently, the D.C.-voltage difference between contacts 12 and 15 (which is the output of the biased weight transducer) would be a measure of the weight on the bit. That voltage difference is continuously applied to the input of converter 16, where the output signal 17 is generated, which has a frequency proportional to the D.C.-voltage difference and, thus, also to the weight on the bit.

Simultaneously, as the rotary table (and hence the bit) turns, the above-described A.C. signal is generated, which completes one cycle every time the rotary table completes one increment of rotary movement. This signal is introduced into the revolutions channel.

Also, as already described above, output from the revolutions channel is a time gate of sufficient voltage level to switch on the totalizing counter 5. It has a preselected time duration determined by capacitor 39 of the "one-shot" operational amplifier 38. Such time duration is sufficiently long to enable a statistically significant number of half-cycles of signal 17 to be counted.

Using the converter noted above it would be generating outputs of 10 to 100 kilohertz for inputs of 10 percent to 100 percent full scale. At the low end of this range a 10-kilohertz signal would have a period of 0.1 millisecond. Consequently, a time gate preselected to last 5 milliseconds would count 50 positive half-cycles at the low end of the range and 500 positive half-cycles at the high end.

The reason for electing to use every other positive half-cycle of signal B, rather than every positive half-cycle can now be explained. For the situation described hereinbefore, where there are 150 electrical cycles per revolution of the rotary table, and for rotary speeds that may be as high as 2 revolutions per second, the frequency of signal A and of signal B will be 300 per second, and the period will be 3.3 milliseconds. If there is to be a time gate of 5 milliseconds initiated by each positive half-cycle of signal B at a rotary speed of 2 revolutions per second, the trigger signals occurring at 3.3-millisecond intervals are too close together to accommodate a 5-millisecond time gate. Consequently, it was decided to employ only every other positive half-cycle of signal B. This allows 6.6 milliseconds, which is sufficient to accommodate the 5-millisecond time gate.

An advantage of this invention is the improved accuracy that can be obtained by the use of combined analog and digital techniques for the measurement of quantities over extended periods of time. This is in comparison with simple analog methods alone, such as the integration of a D.C. signal. It is well-known that D.C. integration suffers by loss of signal over extended periods of time such as 10 to 20 hours, so that accuracy is poor.

In the present invention analog signals are held in storage for only brief intervals, and the conversion of the analog signals to corresponding pulse trains, or to A.C. signals, together with the use of time gates to pass these pulses or cycles to a counter at intervals corresponding to the increments of angular movement of the

bit, obviate the use of D.C. integration and enable the use of a digital integration method of high accuracy.

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

I claim:

1. In rotary drilling operations wherein a drill bit is driven by a rotary drive engine in continuous rotary movement and a varying amount of weight is placed on the bit, the method of continuously deriving a quantity indicative of the wear on the bit, comprising the steps of

initiating a signal of preselected and fixed time duration for each preselected and fixed increment of rotary movement of the bit,

continuously generating a pulse train having a pulse rate proportional to the weight on the bit; and counting said pulses only during each of said signal time durations,

whereby the number of pulses registered by the counter during each such signal time duration is a measure of the product of the weight on the bit and one increment of rotary movement, and the total number of pulses registered by the counter during all such signal time durations is a measure of the sum of all such products, said sum of products being a quantity indicative of the wear on the bit.

2. The method according to claim 1, wherein said preselected and fixed increment of rotary movement of the bit is less than one complete revolution.

3. The method according to claim 2, wherein said pulse train comprises an A.C. signal, of which signal all excursions having a predetermined sign constitute the pulses of the train.

4. The method according to claim 3, wherein each said signal of preselected and fixed time duration is initiated by a time signal from an A.C. tachometer on the rotary drive engine, and said pulse train is derived from a weight transducer connected to the drilling line in combination with a D.C.-to-frequency converter.

5. In rotary drilling operations having a rotary drive engine, wherein the drill bit is in continuous rotary movement and a varying amount of weight is placed on the bit, apparatus for monitoring the wear on the bit comprising in combination

means for generating a pulse train having a pulse rate proportional to the weight on the bit,

means for generating a gate signal having a predetermined time duration once for each predetermined constant increment of rotary movement on the bit, a gated pulse counter having two inputs and being adapted for counting said pulses during each of said gate signals, and

circuit means for connecting said pulse train means to one of said counter inputs and for connecting said gate signal means to the other.

6. The apparatus according to claim 5, wherein said predetermined constant increment of rotary movement of the bit is less than one complete revolution.

7. The apparatus according to claim 6, wherein said pulse train comprises an A.C. signal, of which signal all excursions having a predetermined sign constitute the pulses of the train.

8. The apparatus combination according to claim 7, further including an A.C. tachometer on said engine,

and wherein each said gate signal of predetermined time duration is initiated by a time signal from said A.C. tachometer on the rotary drive engine, and said pulse train is derived from a weight transducer connected to the drilling line in combination with a D.C.-to-frequency converter. 5

9. In rotary drilling operations, wherein a drill bit is maintained in continuous rotary movement by an engine and said drill bit is suspended by a drilling line whereby it may be subjected to a varying amount of weight, and whereby a weight transducer is associated with said drilling line, 10

the combination including means for monitoring the wear on the bit comprising means for deriving from said weight transducer con- 15

nected to the drilling line an A.C. signal having a frequency of the order of tens of kilohertz and proportional to the weight on the bit,

means for generating a gate signal having a predetermined time duration of at least 5 milliseconds once for each predetermined constant increment of rotary movement of the bit, said increment being a fraction of one complete revolution, and said gate signal being initiated by a time signal from an A.C. tachometer on the rotary drive engine; and a gated pulse counter for counting the excursions of said A.C. signal having a predetermined sign during each of said gate signals. 20

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