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METHOD AND APPARATUS FOR MEASURING ROCK BIT WEAR WHILE DRILLING

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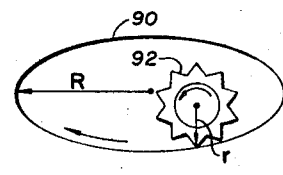
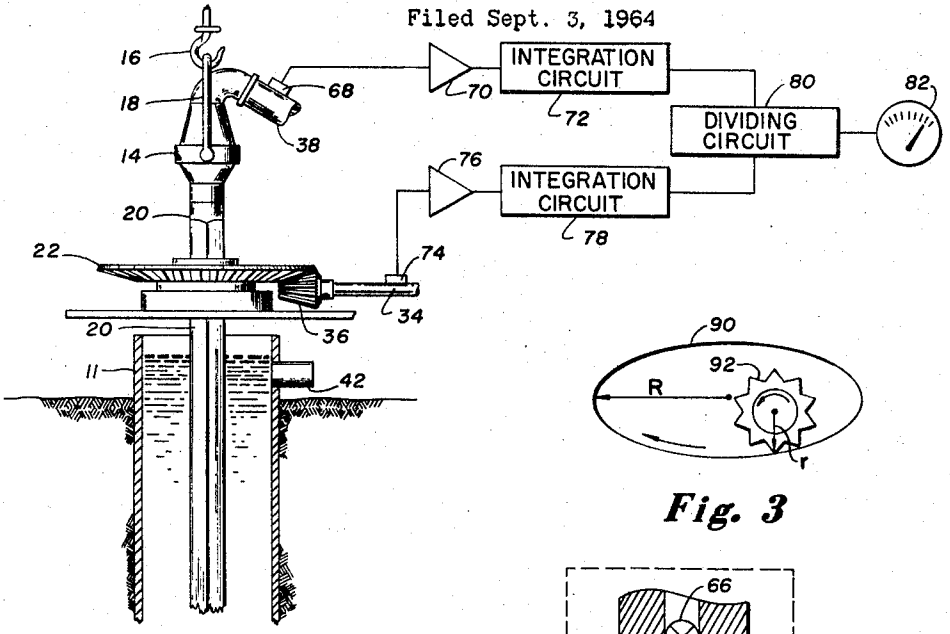


Fig. 3

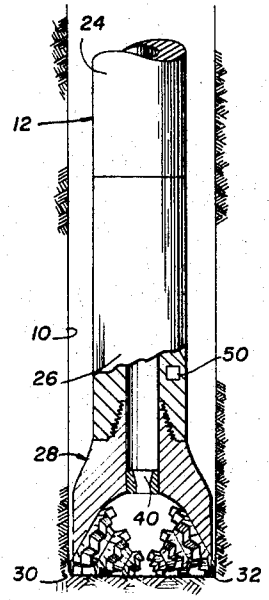


Fig. 1

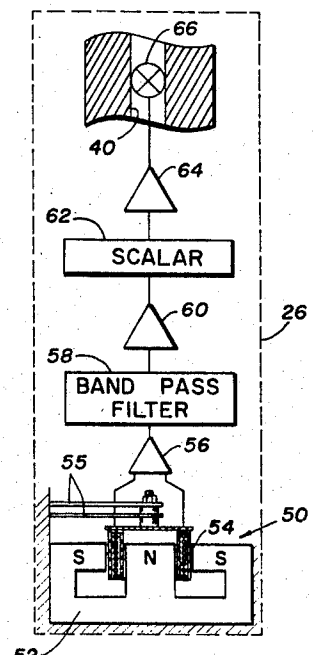


Fig. 2

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1

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METHOD AND APPARATUS FOR MEASURING ROCK BIT WEAR WHILE DRILLING

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The present invention relates to the art of earth boring, and more particularly, but not by way of limitation, relates to a method and apparatus for determining the degree of wear of a cone-type rock bit while the bit is in operation at the bottom of the borehole.

As is well known in the art, the most common type of bit used for drilling oil wells and other boreholes through hard earth formations uses two or more toothed cutting cones or wheels which roll on the bottom of the borehole as the bit is rotated by the drill string. These cutter wheels are provided with hard steel teeth, covered with wear-resistant material. With adequate loading of the cutters by means of the weight of the drill collars above them and the simultaneous rotation of the bit, these cutter teeth in their chipping motion cause a breaking and grinding action on the rock formations. The loosened chips of rock are carried away by the circulating mud fluid, thus cleaning the bottom of the borehole, while the rock bit advances downward.

In order to attain optimum drilling rates, it is important to know the degree of wear of the cutting cones of bit so that the drill string can be rotated at the optimum speed and the optimum weight applied to the bit. The degree of wear of the bit could not heretofore be determined without pulling the entire drill string from the borehole to inspect the bit. This is of course impractical because of the loss of drilling time. Further, drill bits have often been pulled prematurely when the bit passed from a soft to a hard formation, or have been worn beyond the point of effectiveness on the supposition that the slow drilling rate was due to a hard formation, both of which result in a significant loss of drilling time.

In accordance with the present invention, the extent to which a cone-type rotary bit is worn is determined by measuring the relative rotational speeds of the drill string and the rotating cones of the bit. As the teeth of the cones are worn, the rotary cones rotate at a faster speed relative to the rotation of the drill string as a result of the decrease in diameter, and the change in ratio of the two speeds is an indication of wear. More specifically, the rotational speed of the rotary cones may be measured by detecting the dominant frequency with which the teeth of the cones strike the bottom of the borehole as the bit is rotated. The rate of rotation of the bit may be measured at the surface. The rate of rotation of the cones is measured in the borehole and telemetered to the surface, preferably through pressure pulses in drilling fluid in the drill string at time intervals representative of the rotational rate.

The invention further contemplates an apparatus for determining wear of the drill bit which comprises means for sensing the vertical accelerations of the drill bit, means for converting the accelerations to a series of pressure pulses in the column of drilling mud in the drill string at time intervals proportional to the dominant frequency sensed by the accelerometer, means for detecting the pressure pulses at the surface and producing a voltage proportional to the time intervals between the pressure pulses, means for producing a voltage signal proportional to the rate of rotation of the drill string, and means for comparing the voltage signals representative of the dominant frequency of vertical accelerations and the voltage representative of the rate of rotation of the drill bit to produce

2

a signal indicative of wear of the rotary cones of the drill bit.

Therefore, an important object of the present invention is to provide a method and system for determining the extent of wear of a rotary drill bit while the bit is in operation in the bottom of a well bore.

Another object of the invention is to provide a method and system for measuring the rate of rotation of the cutting cones of a rotary drill bit.

A further object of the present invention is to provide a method and system for determining the percent of wear of a rotary drill bit.

Yet another object of the present invention is to provide a system for measuring the rate of rotation of the cutting cones of a drill bit which requires no alteration in the drill bit or abnormal connection to the drill bit.

A further object of the invention is to provide a system of the type described which may be easily used in connection with a standard drilling rig without materially interfering with its normal operation.

Additional objects and advantages of this invention will be evident to those skilled in the art from the following detailed description and drawings, wherein:

FIGURE 1 is a broken, somewhat schematic view of a borehole and rotary drill string illustrating the method and apparatus of the present invention;

FIGURE 2 is a schematic circuit diagram of the down-hole portion of the apparatus of FIGURE 1; and

FIGURE 3 is a schematic drawing which illustrates the mode of operation of the present invention.

Referring now to the drawings, and in particular to the schematic drawing of FIGURE 1, a well bore 10 having surface casing 11 is illustrated as being cut by a drill string 12. The drill string 12 is comprised of a swivel joint 14 having a bail 18 which is suspended by the draw-works hook 16. A square kelly joint 20 passes through a rotary table 22 and is connected by joints of drill pipe (not illustrated) to a series of drill collars 24 which supply the necessary weight for drilling. A telemetering sub 26 is connected in the bottom of the string of drill collars and a conventional rotary-type rock bit 28 is threaded into the lower end of the sub 26. The bit 28 has a pair of cones 30 and 32 which roll on the bottom of the well bore as the drill string is rotated by the rotary table 22 through the shaft 34 and bevel gear 36. Drilling fluid is pumped under pressure through the conduit 38, down through the drill string 12, and out through the passageway 40. The fluid then carries the cuttings up through the annulus around the drill string and out through a connection 42 in the surface casing 11.

The rock bit 28 is of a conventional design and for convenience is illustrated as having only two toothed cutting cones. However it is to be understood that this invention is applicable to bits having any number of rotary cones and in its broader aspects is applicable to bits employing any type of rolling cutters. The cones 30 and 32 have a number of fixed teeth which are alternately disposed in separate rows. The teeth are usually arranged such that only one tooth on any particular cone will impact the bottom of the well bore at one time. This tends to apply the entire load on the bit to the tooth. Since rotation of the cones is not synchronized, the teeth of the several cones contact the bottom of the borehole in random relationship as the bit is rotated, and two or more teeth may on occasion strike the bottom at the same time and thereby vary the frequency. However, the average number of teeth striking the bottom during any selected time intervals will be approximately equal, particularly as the time intervals become greater, and the dominant frequency or average frequency will be related to the rate of rotation of the cones. The bit and lower

portion of the drill string are accelerated vertically at a frequency related to the rate at which the teeth strike the bottom of the well bore, and therefore at a dominant or characteristics frequency related to the rate of rotation of the cutting cones.

In accordance with the broader aspects of the present invention, the rotational speed of the cutting cones may be measured by any means and the measurements communicated to the surface by any suitable means for comparison with the rotational rate of the drill string and therefore with the rotational speed of the drill bit 28.

However, in accordance with an important object of the invention, the rotational speed of the cutting cones 30 and 32 is determined by measuring the dominant frequency with which the teeth of the cutting cones strike the bottom of the well bore, as will now be described in greater detail. The vertical acceleration of the bit 28 and of the lower end of the drill string is detected by an accelerometer 50 which may be conveniently located in the sub 26. The accelerometer 50 may be of the type widely used in geophysical prospecting known as a geophone and is comprised of a permanent magnet 52 rigidly secured to the sub 26 and a coil 54. The coil 54 is spring-mounted between the poles of the magnet 52 by the leaf springs 55 in such a manner as to permit relative vertical movement of the coil 54 and magnet 52 as a result of acceleration of the magnet. The resonant frequency of the spring mounting is selected so as to be primarily responsive to the dominant frequency being detected and may be suitably damped to provide stable operation. Relative motion between the coil 54 and magnet 52 generates an electrical signal which is applied to an amplifier 56.

The amplifier 56 drives a band pass filter 58 which eliminates the frequencies outside the dominant frequency generated by the teeth of the cutting cones 30 and 32. The selected signal passed through the filter 58 is applied to a second amplifier 60 which drives a scalar circuit 62. The scalar circuit 62 produces a series of electrical pulses of relatively low frequency which are applied to the input of a third amplifier 64 which drives a pulsing valve 66. The scalar circuit may perform an integration function so that the total number of pulses from the filter over a relatively long period may be averaged without regard to short time variations in the frequency of the signal resulting from momentary in-phase relationship of the teeth of the several cutters. The pulsing valve 66 is of the type known in the art and produces a pressure pulse in the drilling fluid stream passing down through the drill string by momentarily restricting the passage-way through the sub 26. These pressure pulses instantly appear at the surface due to the incompressibility of the drilling fluid. The scalar circuit 62, amplifier 64, and pulsing valve 66 may be of the type disclosed in Arps Patents Nos. 2,524,031, 2,658,284 and 2,659,046 and in Alder Patent No. 2,898,088.

The pressure pulses in the drilling fluid stream appear at the surface in the conduit 38, which as mentioned is connected to the output of the drilling fluid pump, and are sensed by a pressure transducer 68 and converted to an electrical pulse. The electrical pulses are fed to an amplifier 70 which drives an integration circuit 72. The integration circuit produces an electrical or other signal related to the frequency of the pressure pulses sensed by the transducer 68.

The rotational speed of the drill string and therefore of the bit 28 is detected by a revolution counter 74 or other suitable means which may conveniently be operatively connected to the shaft 34 which drives the rotary table 22. The revolution counter 74 produces a series of electrical pulses having a frequency proportional to the rotational speed of the shaft 34 and therefore to the rotational speed of the rotary table 22, the drill string 12, and the bit 28 which are applied to the amplifier 76. The amplifier 76 drives an integration circuit 78 which

produces an electrical or other signal proportional to the frequency of the pulses. The electrical signals from the integration circuits 72 and 78 are applied to a dividing circuit 80 or other comparison device which produces a signal proportional to the ratio between the rate of rotation of the cutter cones 30 and 32 and the speed of rotation of the drill string. This signal is applied to a suitable indicator 82 such as a volt meter or a recording instrument. The indicator 82 is preferably adjustable so that it may be easily calibrated for purposes which will presently be described.

Referring now to FIGURE 3, a particular row of teeth 92 of a rolling cutting cone, such as the cutting cone 30, for example, having an effective radius r will travel about a circle 90 having radius R . The rate of rotation of the row of teeth 92, and therefore of the cone, will be a function of the radius r and the rate of rotation of the drill bit N . The rate of rotation of the row of teeth may be expressed by the frequency with which the teeth of the row strike the bottom of the borehole. When the bit is new, the effective radius of the cone will be a maximum and the initial frequency F_1 in cycles per second of the vertical shocks, or vertical accelerations generated by the cone in the bit and lower portion of the drill string may be expressed by the equation

$$F_1 = \frac{RN_1T}{r} \quad (1)$$

wherein r is the effective radius of the portion of the cone which travels around the circular path R , N_1 is the rate of rotation of the bit at that time in revolutions per second, and T is the total number of teeth on the particular cone. After the bit has been operated for a period of time, the effective radius of the cone will have been worn by an amount w . Then the frequency F_2 in cycles per second at the later time may be expressed by the equation

$$F_2 = \frac{RN_2T}{r-w} \quad (2)$$

wherein N_2 is the rate of rotation of the drill string at the later time. By combining the Equations 1 and 2, the degree of wear of the rolling cutter cone may be expressed by the ratio

$$\frac{r-w}{r} = \frac{F_1/N_1}{F_2/N_2} = \frac{N_2/F_2}{N_1/F_1} \quad (3)$$

In carrying out this invention, the frequencies of the vertical accelerations may be continuously telemetered to the surface, and the rate of rotation of the drill string continuously measured at the surface. As soon as a new bit is lowered into the borehole and started in operation, the indicator 82 is adjusted or calibrated so that the ratio N_1/F_1 produced by the dividing circuit 80 is equal to a unit value such as 100%. Then at any subsequent point in time, the wear of the bit will be expressed as a percent reduction in radius as represented by

$$\frac{r-w}{r}$$

due to the decrease in the ratio N_2/F_2 . The circuit 80 at the surface determines continuously the ratio N/F which is indicated visually on the dial 82 near the driller. As soon as a fresh bit is run, the driller resets the indicator dial 82 at 100%, representing the full cutter radius r . As drilling proceeds and the radii of the cutter wheels are reduced by wear, the ratio N_2/F_2 decreases, thereby proportionally decreasing the indication N/F on the dial. For instance, if $N_1=1$ revolution per second, F_1 may be measured at 50 cycles per second for a 25 tooth cutter wheel with a radius r of 2 inches, and a value of R of 4 inches. If the cutter wheel has worn down to a radius $r-w$ of 1.5 inches, the frequency F_2 for a rotational speed

5

N_2 of 1.2 revolutions per second would be 80 cycles per second and the reading on the dial would be

$$\frac{1.2/80}{1.0/50} = .75$$

indicating that 25% of the total original diameter had worn off.

The above mathematical expression of the operation of the invention is based upon the frequency generated by the teeth of a single cutting cone. In general, the ideal frequency of the accelerations or shocks of a particular multicone bit will be a function of the total number of teeth of all the cones which strike the bottom of the well bore during a given period. But this ideal frequency will be reduced to the extent that the teeth of two or more cones strike the bottom at the same instant. However, the absolute value of the frequency produced by operation of the bit is unimportant, because the characteristic or dominant frequency of the particular bit, particularly when averaged over a relatively long time period such as one or more revolutions of the bit, will produce a reference value at the indicator which can be calibrated to give the desired reading. Subsequent changes in that reading will then give the desired indication of wear. Thus it is only important that the frequency of the vertical accelerations be directly related to the rate of rotation of the several cutting cones. Even though a particular bit results in slight fluctuations in the reading of the indicator 82 due to variations in the measured frequency of the accelerations, a useful indication of the degree of wear can still be obtained.

From the above detailed description of a preferred embodiment of the invention, it will be evident that a novel method and apparatus has been described for determining the degree of wear of the cones of a rotary rock bit or the like. The rate of rotation of the cones is measured by a system which is not coupled directly to the drill bit other than through the conventional threaded coupling between the bit and the drill collars. Further, the entire frequency measuring and telemetering system may be housed in a single drill collar sub and the data transmitted to the surface through the drilling fluid in the drill string. At the surface, only the pressure pulses in the drilling fluid stream and the rate of rotation of the rotary table need be measured. Thus the system may be used on conventional drill strings without altering the bit, the drill string or the operating procedures in any significant manner. The system may be so designed as to be easily calibrated and interpreted by relatively unskilled labor, and will provide a continuous indication of the degree or percent of wear of the cones of the drill bit during its operation.

Although a preferred embodiment of the invention has been described in detail, it is to be understood that various changes, substitutions and alterations can be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. The method for determining wear of the rotary cutting cone of a rotary bit cutting a borehole which comprises:

detecting the rate of rotation of said bit,
detecting the rate of rotation of said cone during the cutting operation independently of the rate of rotation of the bit, transmitting a signal representative of said rate to a comparing station, and
comparing at said station the rate of rotation of the bit and the rate of rotation of the cone to determine the diameter of the cone, and comparing the determined diameter with a reference diameter.

2. The method for determining wear of the rotary cutting cone of a rotary bit cutting a borehole which comprises:

producing a first signal representative of the rate of rotation of the bit,

6

producing a separate and independent signal representative of the rate of rotation of the cone, transmitting said independent signal to a station for comparison with said first signal,

dividing one signal by the other to determine the diameter of the cone, and comparing the determined diameter with a reference diameter.

3. The method for determining wear of the toothed rotary cutting cones of a rotary bit cutting a borehole which comprises:

producing a first signal representative of the rate of rotation of the bit,

producing an independent signal representative of the dominant frequency at which the teeth of the cutting cones strike the bottom of the borehole, transmitting said independent signal to a station for comparing with said first signal,

dividing one signal by the other to determine the diameters of the cones, and comparing the determined diameters with reference diameters.

4. The method defined in claim 3 wherein:

the frequency measurements are made downhole and the measurements are telemetered to the surface by a series of pressure pulses in the drilling fluid stream at timed intervals proportional to the frequency measured.

5. The method for determining wear of the toothed rotary cones of a rotary bit which comprises:

measuring the initial rate of rotation of the bit,

measuring the initial rate of rotation of the cones, comparing the initial measured rates to produce an initial ratio,

measuring the rate of rotation of the bit at a subsequent point in time,

measuring the rate of rotation of the cones at a subsequent point in time,

comparing the subsequently measured rates to produce a subsequent ratio, and

comparing the subsequent ratio to the initial ratio to provide an indication of wear during the period between measurements.

6. A system for determining wear of the toothed rotary cones of a rotary drill bit cutting a borehole comprising:

means for measuring the rate of rotation of the drill bit and producing a first electrical signal representative of the measured rate,

means independent of said first named means and responsive to vibration caused by the actual cutting operation for measuring the rate of rotation of the cones and producing a second electrical signal representative of the measured rate, and

means for determining the ratio between the two electrical signals to provide an indication of the diameter of the cones.

7. A system as defined in claim 6 wherein the means for measuring the rate of rotation of the cones comprises:

means for measuring the dominant frequency at which the teeth of the cones strike the bottom of the well bore.

8. A system for determining wear of the toothed rotary cones of a rotary drill bit as it is rotated by a drill string through which drilling fluid is pumped comprising:

means for measuring the rate of rotation of the drill bit and producing a first electrical signal representative of the measured rate,

an accelerometer for producing a second electrical signal representative of the vertical accelerations of the drill bit,

means for producing pressure pulses in the drilling fluid at timed intervals representative of the dominant frequency of the second electrical signal,

means for detecting the pressure pulses and producing a third electrical signal representative of the time intervals between the pressure pulses, and

means for comparing the first and third electrical sig-

7

nals to provide an indication of the diameter of the rotary cones and therefore of the degree of wear of the cones.

9. A system as defined in claim 8 wherein:
the accelerometer and the means for producing pressure
pulses are disposed in a drill cutter sub in the drill
string. 5

10. The method for measuring change in the rate of
rotation of the toothed cutting member of a bit relative
to rotation of the bit as a whole as it cuts a borehole
which comprises measuring from time to time the chang-
ing rate at which the teeth of the member impact the
bottom of the borehole and comparing said changing 10

8

rate with a basically unchanging rate at which the bit as
a whole is rotated.

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