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Montgomery et al.

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[45] **Oct. 1, 1974**

[54] **METHOD AND APPARATUS FOR MONITORING WELL PUMPING UNITS**

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[73] Assignee: **Mobil Oil Corporation,** New York City, N.Y.

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[52] **U.S. Cl.** **73/151**
[51] **Int. Cl.** **E21b 47/00**
[58] **Field of Search** .... 73/151, 141 R, 141 A

[56] **References Cited**

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2,107,151	2/1938	Higginson	73/151 X
2,163,665	6/1939	Carr et al.	73/151
2,661,697	12/1953	Long et al.	73/151 UX

Primary Examiner—Jerry W. Myracle
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[57] **ABSTRACT**

Method and apparatus for monitoring the operation of a sucker rod-type pump employed in withdrawing fluids from a well. A transducer is employed to generate a signal representative of the load in the pumping unit as the rod string is reciprocated to operate a downhole pump. This signal is differentiated in order to produce a derivative function which is representative of the rate of change of the load signal. The derivative function is analyzed to detect indications of fluid pounding of the well. When a given condition of fluid pounding is encountered, a monitor function is produced which is employed to initiate action such as temporarily shutting down the pumping unit or activating an alarm. The signal from the transducer also is analyzed for a normal high load amplitude and for amplitudes which fall outside of a desired maximum-minimum load range. The invention may be implemented by hardwired or software systems.

27 Claims, 5 Drawing Figures

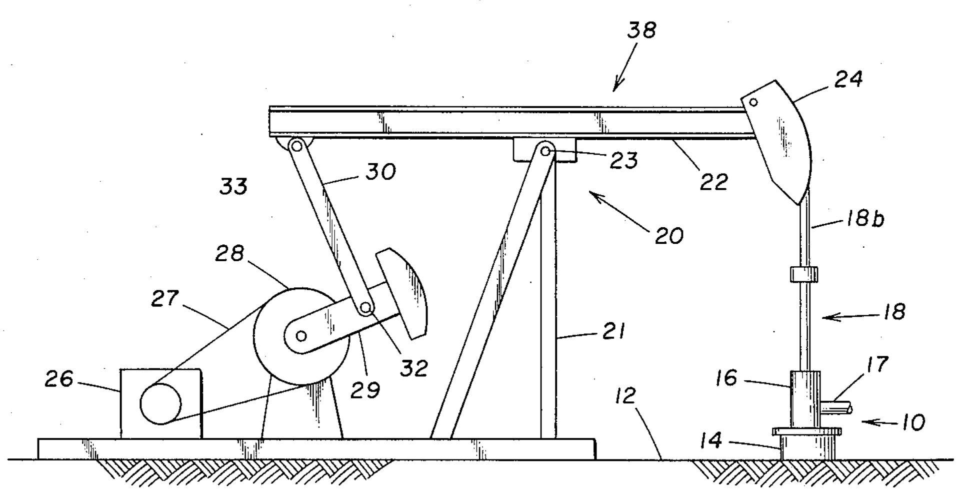
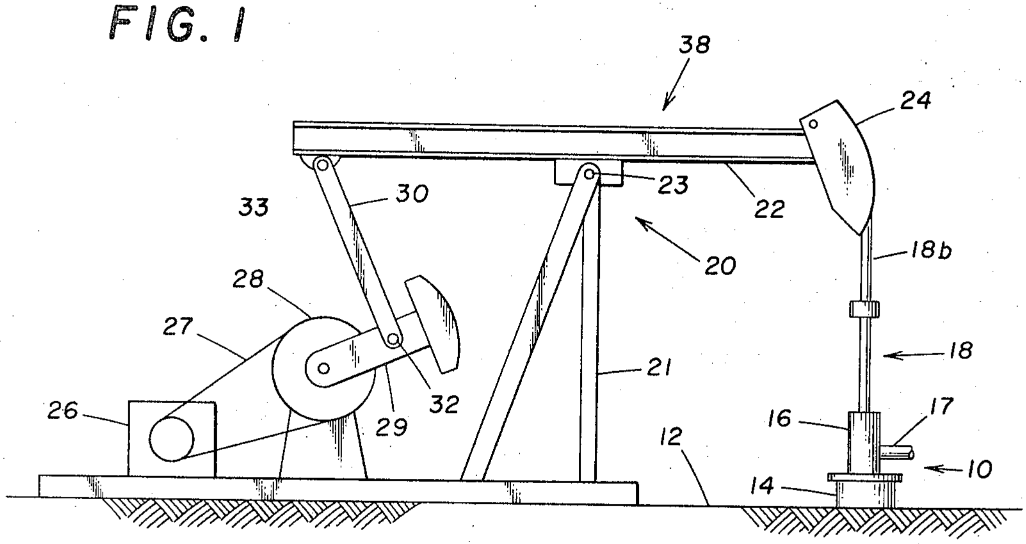


FIG. 1


38
24
30
23
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33
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18b
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27
18
21
32
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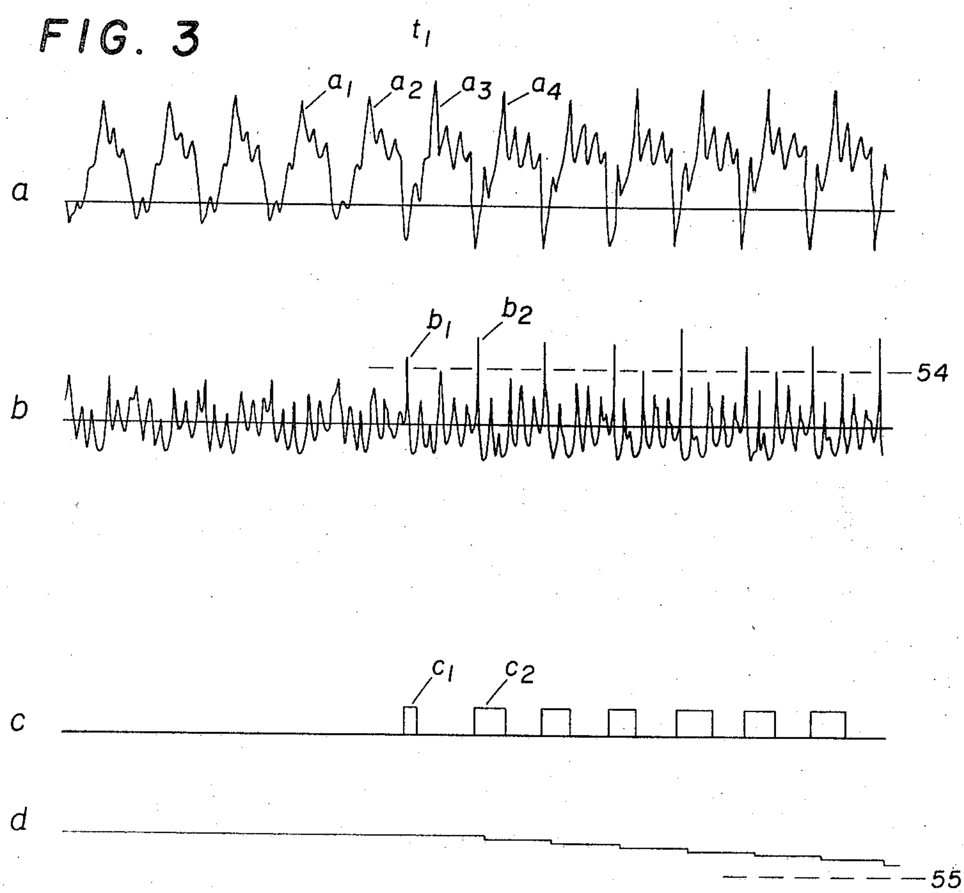
17
16
26
12
10
14

FIG. 3


t1
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a3
a4
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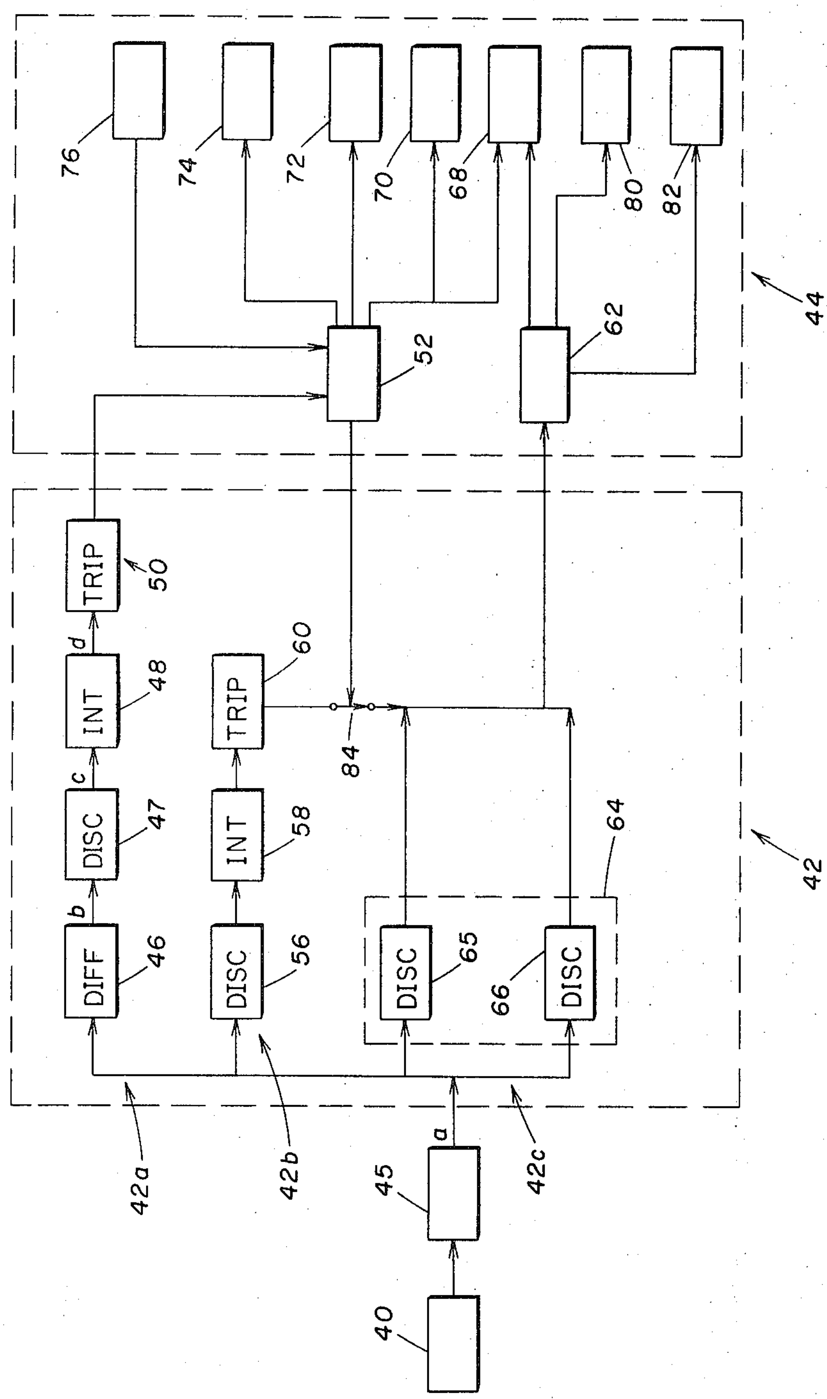
b1
b2
54
b
c1
c2
c
d
55

FIG. 2


DIFF
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TRIP
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TRIP
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b
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42c
44
45
46
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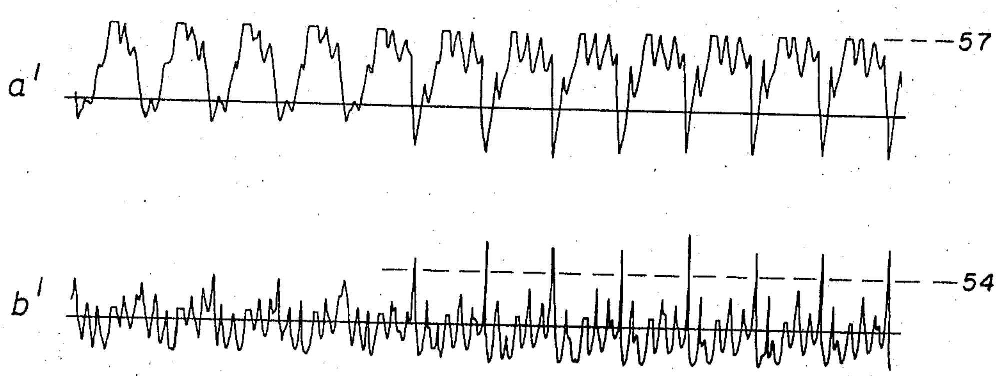
76
80
82
84

FIG. 4


a'
b'
57
54

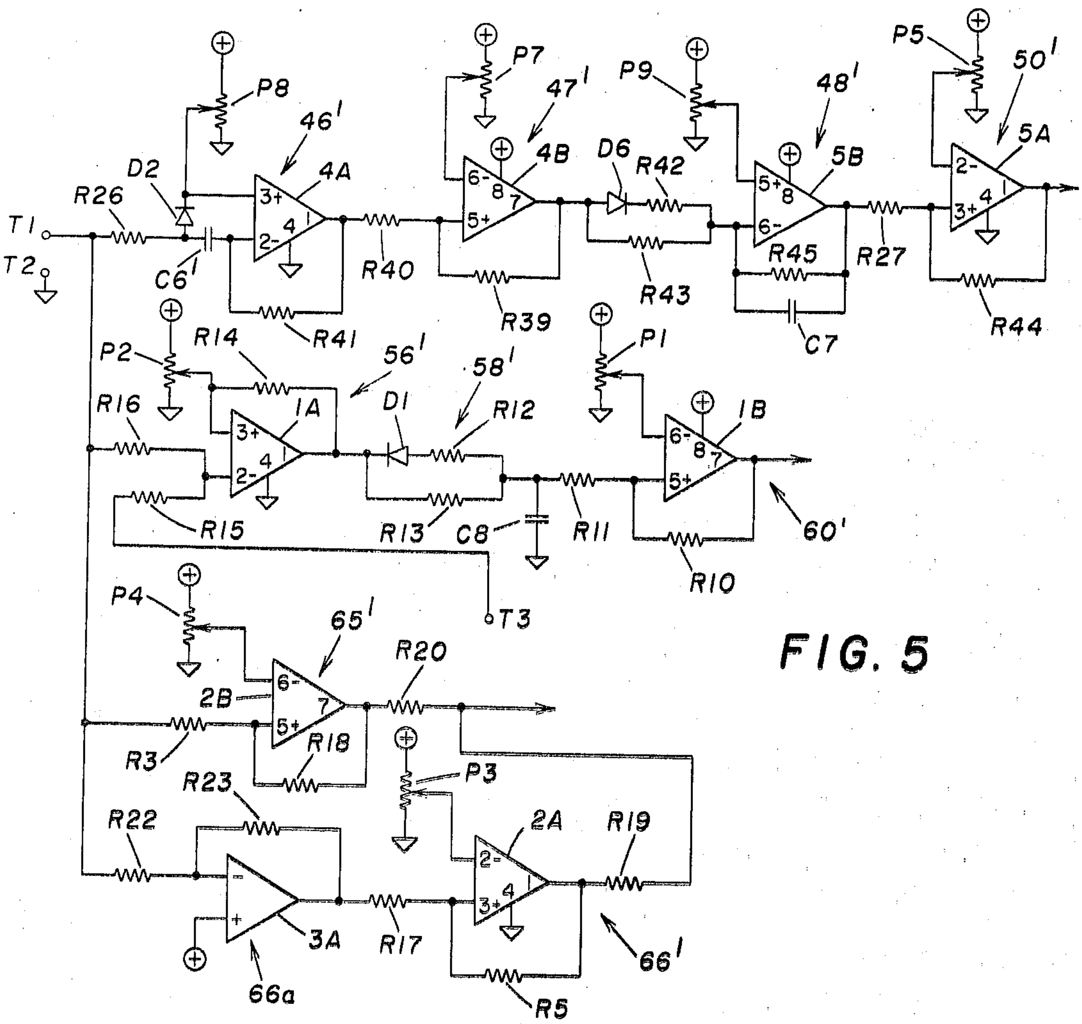

T1
T2
R26
D2
C6'
P8
46'
4A
3+
2-
4
1
R40
R41
P7
47'
4B
6-
8
7
5+
R39
D6
R42
R43
P9
48'
5B
5+
6-
R45
C7
R27
P5
50'
5A
2-
3+
R44
P2
R14
56'
1A
R16
R15
D1
58'
R12
R13
C8
R11
P1
1B
60'
R10
T3
P4
65'
2B
R20
R3
R18
P3
R23
R22
2A
R19
3A
R17
66a
R5
66'

FIG. 5

METHOD AND APPARATUS FOR MONITORING WELL PUMPING UNITS

BACKGROUND OF THE INVENTION

This invention relates to the monitoring of sucker rod-type well pumping units and more particularly to processes and systems for monitoring the operation of such units by operating on a transducer signal representative of load changes in the units.

Sucker rod-type pumping units are widely used in the petroleum industry in order to recover fluids from wells extending into subterranean formations. Such units include a sucker rod string which extends into the well and means at the surface of the well for reciprocating the rod string in order to operate a downhole pump. Typical of such units are the so-called "beam-type" pumping units. In a beam-type pumping unit the sucker rod string is suspended at the surface of the well from a structure consisting of a sampson post and a walking beam pivotally mounted on the sampson post. The sucker rod string normally is connected at one end of the walking beam which is connected also to a prime mover through a suitable crank and pitman connection. Thus by this arrangement the walking beam and the sucker rod string are driven in a reciprocal mode by the prime mover.

In order to analyze and/or control the performance of a well produced by means of a rod-type pumping unit, it is a conventional practice to measure, either directly or indirectly, the load on the rod string as the unit is in operation. One particularly useful system by which this may be accomplished is disclosed in U.S. Pat. application Ser. No. 58,439, entitled WELL MONITORING APPARATUS, filed July 27, 1970, by Richard C. Montgomery and Jacque R. Stoltz, the inventors herein. In the system disclosed in said application Ser. No. 58,439 a transducer is secured to the walking beam of a beam pumping unit in order to generate a signal representative of the load in the beam as it is reciprocated. The load changes in the beam in a representative and repeatable relationship with the load in the sucker rod string such that the information derived from the transducer may be employed to characterize the well as to normal or abnormal operating conditions. The transducer signal may be recorded for future analysis or it may be used for real time control of the pumping unit.

Another more conventional technique for obtaining an indication of load measurements in the sucker rod string is to employ a transducer, commonly termed a "pump dynamometer," which is attached directly in the sucker rod string, normally in the "polished rod" section thereof. For example, U.S. Pat. No. 3,359,791 to Pantages discloses a pump dynamometer which is mounted in the polished rod section of the rod string and which functions to generate an alarm or to initiate a control action in response to the dynamometer output reaching a condition of an abnormally high or low load on the polished rod or failing to reach a condition representative of an intermediate normal load condition within a specified time interval. Thus when the control system in Pantages indicates an abnormally high or abnormally low load condition, a signal is generated to shut down the pump. Signals indicative of normal operating loads are applied through time delay devices such that if such signals are not received within a given time interval appropriate action may be taken such as shutting down the pump or activating an alarm. It has also been proposed to take such control measures through the action of a central control facility. For example, as described by Boggus, C. C., "Let's Weigh Those Wells Automatically," OIL & GAS JOURNAL, Vol. 62, No. 5, Feb. 3, 1964, p. 78, the output from a large number of pump dynamometers can be applied to a central computer which is programmed to take appropriate control actions.

One abnormal pumping condition to which much attention has been given is the phenomenon termed "fluid pounding." Fluid pounding occurs when the well pumps off, i.e., when fluid is withdrawn from the well at a rate greater than the rate at which it enters the well from the formation. When this occurs, the working barrel of the downhole pump is only partially filled during an upstroke of the plunger. Then on the downstroke the plunger strikes or "pounds" the fluid in the working barrel. This causes severe jarring of the entire pumping unit, including the rod string and the surface equipment, which ultimately may lead to failure of the unit.

Various techniques have been proposed for monitoring a rod-type pumping unit in order to avoid or sense the fluid pound condition. Exemplary of such systems is the one disclosed in U.S. Pat. No. 3,509,824 to Schmidly which may be employed for pumping units in which an electric motor is employed as the prime mover. This system employs a transducer which generates an output signal indicative of the power demand of the motor. The output from the transducer is applied to an "overload sensor" which takes appropriate control action in the case of an unacceptable power demand by the electric motor. The output from the transducer also is applied to an "underload sensor" which is indicative of low power consumption of the motor such as may be due to fluid pounding. A pulse signal output from the underload sensor is applied through a gating arrangement to a pulse integrator which does not time out so long as the underload sensor fails to detect low power consumption indicative of an unacceptable condition of fluid pounding.

Another type of system for detecting fluid pounding is disclosed in U.S. Pat. No. 3,559,731 to Stafford. The Stafford system employs a flow indicator in the flow line leading from the wellhead to the surface gathering system. The output from the flow indicator is applied through a suitable time delay relay such that if fluid flow does not occur through the flow line within a desired time interval, the delay trips to shut in the well. Various other systems have been employed to detect fluid pounding of a pumping unit or conditions commonly associated with fluid pounding. For a further description of such systems, reference is made to U.S. Pat. Nos. 3,075,466 to Agnew et al., 3,269,320 to Tilley et al., and 3,306,210 to Boyd et al.

SUMMARY OF THE INVENTION

This invention provides new and improved methods and apparatus for monitoring the operation of a well pumping unit of the type employing a sucker rod string and means to reciprocate the rod string to operate a downhole pump. In carrying out the invention, there is employed a transducer to generate a signal representative of a changing load in the pumping unit as the rod string is reciprocated. The signal from the transducer is operated on to produce an operating function which is representative of the rate of change of the load signal. A monitor function, otherwise referred to herein as a control function, is then generated in response to the operating function reaching a condition indicative of a specified condition of fluid pounding which is deemed undesirable. This monitor or control function may be employed to initiate appropriate control and/or alarm action.

In a further aspect of the invention, the load signal also is operated upon to amplitude discriminate the load signal with respect to a given high amplitude discrimination value indicative of a minimum acceptable high load condition. A monitor or control function is generated upon the failure of the load signal failing to reach this value within a desired frequency condition.

In yet a further embodiment of the invention, the load signal also is compared with an amplitude range having upper and lower amplitude limits which are above and below, respectively, the aforementioned amplitude discrimination value. A monitor or control function is generated in response to the amplitude of the load signal falling outside of this range which corresponds to acceptable high and low load conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an illustration of a well equipped with a sucker rod-type pumping unit.

FIG. **2** is an illustration showing in block diagram the functional components of a preferred embodiment of the invention.

FIG. **3** is an illustration of waveforms as they may appear in certain locations of the diagram of FIG. **2.**

FIG. **4** is an illustration of waveforms which appear in a further embodiment of the invention.

FIG. **5** is an electrical schematic of an embodiment of the invention employing hardwired logic circuitry.

DESCRIPTION OF SPECIFIC EMBODIMENTS

Perhaps the most commonly employed rod pumping units are beam units of the so-called "conventional type" and the invention will be described in detail with respect to its use in conjunction with this type of unit. Referring first to FIG. **1,** there is illustrated the wellhead **10** of a well which extends from the earth's surface **12** into a subterranean oil producing formation (not shown). The wellhead comprises the upper portions of a casing string **14** and tubing string **16.** The tubing string extends from the wellhead to a suitable depth within the well, e.g., adjacent the subterranean formation. Liquid from the well is produced through the tubing string **16** by means of a downhole pump (not shown) to the surface where it passes into a flowline **17.**

The downhole pump is actuated by reciprocal movement of a sucker rod string **18.** Rod string **18** is suspended in the well from a surface support unit **20** comprising a sampson post **21** and a walking beam **22** which is pivotally mounted on the sampson post by a pin connection **23.** The sucker rod string includes a polished rod section **18*a*** which extends through a stuffing box (not shown) at the top of the tubing string and a section **18*b*** formed of flexible cable. The cable section **18*b*** is connected to the walking beam **22** by means of a "horsehead" **24.**

The pumping unit is driven by a prime mover **26** such as an electric motor. The prime mover drives the walking beam through a drive system which includes a belt drive **27,** crank **28,** crank arm **29,** and a pitman **30** which is pivotally connected between the crank arm and walking beam by means of pin connections **32** and **33.** The outer end of crank arm **29** is provided with a counterweight **35** which balances a portion of the load on the sucker rod string in order to provide for a fairly consistent load on the prime mover.

It will be recognized that the well structure and pumping equipment thus far described are conventional and merely exemplary, and that the present invention may be employed with respect to other suitable rod-type pumping units. For a more detailed description of such equipment, reference is made to Uren, L. C., PETROLEUM PRODUCTION ENGINEERING — OIL FIELD EXPLOITATION, Third Edition, McGraw-Hill Book Company, Inc., New York, Toronto, and London, 1953, and more particularly to the description of rod-type pumping units appearing in Chapters VI and VII thereof.

Turning now to FIG. **2,** there is illustrated in block diagram a preferred embodiment of the present invention. This embodiment comprises a transducer **40** which may be connected to the pumping unit at any appropriate location as described hereinafter, an operating unit **42** to which the transducer signal is applied, and a control unit **44** which responds appropriately to control functions from the operating unit. The operating unit comprises a first section **42*a*** which functions to generate a control function indicative of a fluid pound condition, a second section **42*b*** which generates a control function when the signal from the transducer fails to reach a desired high normal load condition, and a third section **42*c*** which generates a control function when the load signal exceeds a maximum limit or falls below a minimum limit.

The transducer may be of any suitable type and may be positioned on the pumping unit on any component in which the stress or load changes in a representative repeatable manner with load changes in the rod string. An obvious location for the transducer is, of course, in the rod string itself. However, it normally will be desirable to employ a transducer of the type described in the aforementioned application Ser. No. 58,439 and to locate the transducer on a load-bearing support structure as taught in that application. A preferred location for the transducer is on the walking beam in the area generally located by reference character **38,** between the pivotal connection of the beam on the sampson post and the horsehead connection.

The operation of the invention will be described in detail with reference to FIG. **2** and with reference to the waveforms shown in FIG. **3.** The several waveforms illustrated and the respective points at which they appear in FIG. **2** are designated by common reference characters in FIGS. **2** and **3.** Referring first to FIG. **2,** the transducer **40** generates an output signal representative of load changes in the pumping unit as the rod string is reciprocated. The output signal from the transducer may vary, for example, in proportion to the strain induced in the component upon which it is mounted, within the range of 0 to 25 millivolts d.c. The transducer signal is applied through a high gain d.c. amplifier **45** in order to provide a more easily usable load signal, e.g., one within the range of 0 to 5 volts d.c. This signal is applied to sections **42*a*, 42*b*,** and **42*c*** of the operating unit.

In section 42*a* the load signal from the transducer is first operated upon in order to arrive at a function representative of the rate of change of the signal. This is accomplished in the preferred embodiment of the invention by applying the signal to a differentiator **46** which produces a time derivative of the load signal. The amplitude of the derivative function increases as the slope, or rate of change, of the load signal increases.

The output from differentiator **46** is applied to an amplitude discriminator **47** which functions to amplitude discriminate the derivative signal to produce a residual output function representative of a predetermined fluid pound condition. Specifically, discriminator **47** may take the form of a comparator which compares the differentiator output with a preset reference voltage which corresponds to a desired discrimination value. Thus each time the rate of change of the transducer signal is such as to result in a differentiator output above the specified discrimination value, a residual signal pulse is produced by the amplitude discriminator.

The output from the amplitude discriminator **47** is accumulated until it reaches a constraint indicative of an unacceptable fluid pound condition, at which time a control signal is generated. More specifically, the residual function from discriminator **47** is applied to an integrator **48** equipped with a follower trip unit **50.** When the accumulated residual pulses from discriminator **47** reach a specified constraint, such as may be determined by the time constant of the integrator and the activation level of the trip unit **50,** a control signal is applied to a "pump off" relay **52** in control unit **44.** Relay **52** then initiates appropriate actions as described hereinafter.

Preferably, the residual function from amplitude discriminator **47** comprises a plurality of pulses which are characteristically proportional to the amplitude differentials between corresponding peaks of the derivative function and the voltage level at which the amplitude discriminator **47** is set. Thus the pulses from discriminator **47** are proportional in a characteristic such as amplitude or duration, or the product of amplitude and duration, to amounts by which the peaks of the signal from the differentiator exceed the discrimination value. This mode of operation is advantageous since the constraint at which the integrator trip operates will then relate quantitatively to the rate of occurrence of fluid pounding and also to the magnitude of such fluid pounding. Thus, for a given setting of the integrator trip **50,** the control function will be generated upon the occurrence of a given number of moderate pounding conditions, or upon the occurrence of a lesser number of more severe pounding conditions.

Turning to FIG. **3,** the operation of the differentiator, amplitude discriminator, and integrator can best be understood by referring to curves *a*, *b*, *c*, and *d* which are analog values with amplitude in ordinate and time in abscissa. In FIG. **3,** curves *b*, *c*, and *d* are shown in reverse polarity with respect to curve *a* to provide for easy reference. At time t_1, the load signal *a* begins to decrease unusually rapidly to a low load condition thus indicating the occurrence of fluid pounding. This rapid change in load is reflected in the differentiator output *b* which exceeds the reference voltage setting of amplitude discriminator **47** (indicated by broken line **54**). The residual pulse output from the amplitude discriminator is indicated by curve *c*. As is evident from an examination of curves *b* and *c*, the pulses in curve *c* are of common amplitude, but vary in duration in proportion to the amplitude differentials between the corresponding peaks of signal *b* and discrimination level **54.** For example, the relief of peak b_1 of the differentiator output signal in excess of level **54** is about one-third of the relief of peak b_2. Thus, the duration of pulse c_1, corresponding to peak b_1, is about one-third of the duration of pulse c_2, corresponding to peak b_2. It is preferred to employ pulse duration as the proportional characteristic since by keeping the pulse amplitude relatively constant, the integrator response is more repeatable in following the time integral of the applied pulses.

The output from integrator **48** is illustrated by curve *d* of FIG. **3.** As shown, the integrator output remains flat so long as the differentiator output is flat. When the differentiator output exceeds the discrimination level **54,** the charge on integrator **48** builds up in proportion to the time integrals of pulses c_1, c_2, etc. When the integrator trip level (indicated by broken line **55**) is reached, a control signal is applied to relay **52.** If fluid pounding ceases before the trip level is reached, the integrator will begin to discharge and the output will return to its former level.

From an examination of curve *a* of FIG. **3,** it will be noted that the transducer signal also undergoes a relatively rapid change during the upstroke of the sucker rod string. this is indicated by segments a_1–a_4 of curve *a* which reflect decreases in load which may be encountered in normal operation. Depending upon the speed at which the rod string is reciprocated this load change rate during the upstroke of the load may approach and sometimes even exceed the load change rate which is indicative of a fluid pound condition. In a preferred embodiment of the invention, possible erroneous indications from this phenomenon are avoided by equipping the differentiator with an initial clipping unit which prevents the peak amplitude of the applied load signal from exceeding a predetermined value. The clipping unit is set to a reference limit significantly below the maximum amplitude of the load signal. Preferably, the clipping unit is set to a reference value which is less than the discrimination value employed for the normal maximum load determination described in detail below. The clipping unit reference will, of course, be greater than the low load limit employed in section **42***c*.

The waveforms associated with this embodiment of the invention are in FIG. 4 with curve *a'* illustrating the clipped load signal and curve *b'* the attendant differentiator output. As shown by curve *a'*, the load signal is clipped at a reference level **57,** thus eliminating the signal in excess of this amplitude. The clipped signal is then applied to the differentiator in order to produce the differentiator output *b'*. As can be seen by an examination of these signals, the rapid change in the transducer signal during the upstroke of the rod string will not be reflected in the differentiator output.

To summarize briefly the operation of section **42***a*, the load signal is differentiated and the resulting derivative is amplitude discriminated to detect peak values indicative of fluid pounding. This residual is then integrated and when the integral reaches a predetermined value, the control function is generated. From the foregoing description it will be recognized that the integration step may be omitted and fluid pounding can still be detected by responding directly to the amplitude discrimination of the derivative. However, the integration step is highly advantageous since it permits a quantitative determination with respect to both the frequency and severity of the fluid pounding.

Turning now to the operation of the invention with regard to the normal maximum load determination, the load signal from amplifier 3 is applied to an amplitude discriminator **56.** Amplitude discriminator **56** is set with a relatively high amplitude discrimination value which is slightly below the maximum amplitude of the load signal encountered during normal operation of the pumping unit. Thus, during normal operation of the pumping unit, the discriminator **56** will produce a residual function comprised of one pulse for each cycle of operation of the pumping unit.

The output from discriminator **56** is applied to a timing circuit which is reset by each pulse and which times out to generate a control function if it is not reset within a desired time interval. More specifically, the timing circuit comprises a passive integrator **58** equipped with a follower trip unit **60.** Integrator **58** continuously charges in one direction and if it is not reset by the residual signal from the amplitude discriminator within a given interval, the integrator output will reach the level required to actuate trip **60.** Thus it can be seen that if the load in the pumping unit does not reach some minimum value (corresponding to the discrimination level for discriminator **56**) within a desired frequency, trip **60** will operate to generate a control function. This control function is applied to a unit malfunction relay **62** in control unit **44.**

In addition to the fluid pound and maximum normal load analyses, the present invention also provides means for analyzing the load signal for amplitudes indicative of unacceptably high or low loads in the pumping unit. This is accomplished by applying the load signal to a comparator which functions to compare the load signal with an amplitude range having upper and lower amplitude limits. Upon the amplitude of the load signal falling outside of this range, the comparator unit generates a control function which is applied to the unit malfunction relay **62** in control unit **44.**

The comparator circuit unit **64** comprises parallel-connected amplitude discriminators **65** and **66.** Amplitude discriminator **65** is set to a discrimination level above the discrimination level for discriminator **56** and above a signal level associated with acceptable maximum loads. Discriminator **66** is set to a low discrimination level below the discrimination level of detector **56** and below a signal level associated with acceptable minimum loads. Thus in operation of the comparator unit, the load signal is compared with a high preset reference voltage and should the load signal exceed this voltage, a control signal is generated for application to relay **62.** The load signal also is compared in discriminator **66** with a low reference voltage and upon the signal dropping below this reference voltage, a control function is similarly generated and applied to relay **62.**

In the control unit **44,** the primary control responses are taken by the pump-off relay **52** and the unit malfunction relay **62.** When a control signal indicative of fluid pounding is applied to relay **52,** this relay functions to activate a unit shut down relay **68.** This relay then acts, e.g., by opening contacts in a power supply circuit if the prime mover is an electric motor, to shut down the prime mover. The relay **52** also closes contacts in an alarm circuit **70** in order to energize an alarm, which typically may take the form of a visual indicator. In addition, relay **52** acts to shut down a totalizer **72** which records the running time of the pumping uniit. Thus, if the unit intermittently pounds and is shut donw, totalizer **72** will indicate only the time during which the unit is actually pujping. Relay **52** also activates a shut down timer **74.** Timer **74,** which may be a conventional electromechanical timer, is set to run for a preset time interval which will allow sufficient fluid to accumulate in the well to avoid pounding. When timer **74** times out, it trips a relay **76** which then functions to reset relay **52** to its former state. The actions applied to relay **68,** alarm **70,** and the run time totalizer **72** are then released, and these units return to their former states. The pumping unit then resumes operation until such time as pounding may again occur.

The unit malfunction relay **62** responds to an applied control function to turn on an alarm **80** and to actuate unit shut down relay **68.** The unit in this situation remains down until relay **62** is manually reset by trip means **82.**

The control function initiated by integrator trip **50** is also employed to disable the operation of the normal maximum load section **42*b*.** This avoids, during the time that the pumping unit is shut down to alleviate the fluid pounding condition, the generation of a control function by section **42*b*.** This may be accomplished by action of the pump-off relay **52,** as shown schematically in FIG. **2.** Thus when a control signal indicative of the fluid pounding is applied to relay **52,** this relay acts to open a switch **84** in the output from the integrator trip **60.** When relay **76** acts to return the pump-off relay to its former state, switch **84** will be closed.

The present invention can be carried out employing a "hardwired" system as discussed in greater detail hereinafter, located at the well site. This normally will be desirable where individually isolated wells are to be monitored. The invention can also be carried out by employing a properly programmed digital computer to implement the analysis and control functions described above with respect to operating unit **42.** This mode of operation is advantageous where a large number of wells in an area can be placed under the control of a central facility.

A digital computing system which is suitable for use in carrying out the invention is the Data General Corporation "Nova" minicomputer equipped with a 16-bit bidirectional IO bus which provides for input into the computer and interfacing between the computer and a master supervisory control system. Suitable master and remote terminal units which may be employed are available from Baker Automation Systems, Inc. as the "RDACS" Master/Remote system.

In operation, the computer initiates instructions and receives information through the master and remote terminal units to effect monitoring and control actions with respect to a given well. For example, the load signal from the tranducer on the pumping unit may be interrogated at 0.2-second intervals for a period of 10 seconds. At each interrogation, the analog output from the transducer is converted to a digital value by the remote terminal unit and transmitted to the master unit and computer for analysis by the computer. The computer is, of course, programmed to perform numerically the various analytical operations described previously in analog format and to transmit instructions initiating the appropriate control functions for application to the control unit **44**, located at the well site.

FIG. **5** illustrates specific circuits which may be employed in a hardwired operating unit **42.** The circuits in FIG. **5** which correspond to the components shown functionally in FIG. **2** are identified by the prime (') of the reference characters used in FIG. **2.** With reference to FIG. **5**, the load signal from amplifier **45** (shown in FIG. **2**) is applied across terminals T1 and T2 to differentiator **46'** which is equipped with an initial clipping circuit comprising a resistor **R26,** diode **D2,** and a variable reference potentiometer **P8.** Potentiometer **P8** is set to the desired reference voltage and signal amplitudes greater than this reference are not allowed to pass to the capacitor **C6.** The differentiator **46'** comprises an amplifier 4A and a feedback resistor **R41** in addition to capacitor **C6.** The first time derivative of signals presented at capacitor **C6** is available at the output, "pin **1,**" of amplifier 4A.

The differentiator trip **47'** is comprised of an input resistor **R40,** amplifier 4B, variable reference potentiometer P7, and positive feedback resistor **R39.** The output of amplifier 4B attains its maximum positive value whenever the input to R40 exceeds the reference voltage set by potentiometer **P7.** The output of amplifier 4B returns its minimum (maximum negative) value when the input to resistor **R40** declines to a value less than the reference voltage.

The signal from amplifier 4B is applied to integrator **48'** which includes amplifier 5B, variable reference potentiometer P9, feedback capacitor C7, resistors **R42** and **R43,** and diode **D6.** Diode D6 and low level resistor R42 control the integration rate when maximum or pulse input voltage is present. High level resistor **R43** determines the integration rate when a minimum input occurs. The trip circuit **50'** for integrator **48'** comprises an input resistor R27, variable reference potentiometer **P5,** amplifier 5A, and positive feedback resistor **R44.** The output of amplifier **5**A assumes its maximum positive value when the input to resistor **R27** exceeds the reference voltage or "trip level" set by potentiometer **P5** and remains at its minimum value when the input to resistor **R27** is less than this reference voltage. This output is applied to unit shut down relay **52.**

The load signal also is applied to amplitude discriminator **56'** for the normal maximum load determination. This unit includes an amplifier **1**A, variable reference potentiometer P2, positive feedback resistor **R14,** input resistor **R16,** and override resistor **R15.** When the well is pumping, the output of amplifier **1**A goes to its maximum negative value when the signal input to resistor **R16** exceeds the reference voltage determined by potentiometer **P2** and returns to its previous value when the signal input falls below this voltage. The integrator **58'** is comprised of capacitor **C8,** resistors **R12** and **R13,** and diode **D1.** Low level resistor **R12** and the diode **D1** determine the discharge rate of capacitor **C8** and high level resistor **R13** determines the charging rate. The integrator trip circuit **60'** comprises an amplifier **1**B, variable reference potentiometer **P1,** input resistor **R11,** and positive feedback resistor **R10.** Amplifier **1**B attains its maximum output when the voltage on capacitor **C8** exceeds the voltage set by potentiometer **P1** and this output is fed to relay **62.**

When the pumping unit is shut down by the pump-off relay (shown in FIG. **2**), a voltage signal is applied at terminal T3 to resistor **R15** in order to disable section **42***b* from its normal operation. This voltage signal is sufficiently greater than the reference voltage determined by potentiometer P2 so that the absence of a normal maximum load signal during this time does not result in activation of the integrator trip **60'**. When the well returns to normal operation, the voltage to resistor **R15** is removed. Thus it can be seen that this operation is equivalent to the opening and closing of switch **84** as described above with reference to FIG. **2.**

The high load amplitude discriminator **65'** is comprised of amplifier **2B**, a variable reference potentiometer P4 set to a "high load" voltage, input resistor **R3,** and positive feedback resistor **R18.** The output of amplifier **2B** attains its maximum value if the input to resistor **R3** exceeds the set point. So long as the load signal input to resistor **R3** does not exceed the reference voltage, the output of amplifier **2B** remains at its minimum value. The output of high load detector **65** is supplied to relay **62.**

The transducer signal also is applied to low load amplitude discriminator **66'**. Discriminator **66'** functions similarly as discriminator **65'**, but is equipped with an initial inverter **66***a* comprising input resistor **R22,** amplifier 3A, and feedback resistor **R23.** Inverter **66***a* acts to reverse the polarity of the load signal before it is applied to input resistor **R17.** Thus the output of amplifier **2A** goes to its maximum value when the input to resistor **R17** exceeds the reference voltage determined by potentiometer P3 and corresponding to the minimum acceptable load. The output from the amplifier **2A** is supplied to relay **62.**

In the system shown in FIG. **5**, the following circuit parameters may be used. Resistors **R3, R15, R16, R27,** and **R40** — 22 kilohms; **R5, R11, R14, R18, R39,** and **R44** — 330 kilohms; **R10** — 2.1 megohms; **R12, R22,** and **R23** — 10 kilohms; **R13** and **R45** — 2.2 megohms; **R17, R41,** and **R43** — 6.8 megohms; **R19** and **R20** — 5.1 kilohms; and **R26** and **R42** — 47 kilohms. Capacitors **C6** and **C7** are rated at 25 volts with capacitances, respectively, of 2 microfarads and 30 microfarads. Capacitor **C8** is a 50-volt 250 microfarad capacitor. Each of diodes **D1, D2,** and **D6** is type number IN4009. Potentiometers **P1–P9** are rated at 20 kilohms and each of the amplifiers described is an N5558T integrated circuit.

What is claimed is:

1. In a method of monitoring the operation of a well produced by the operation of a pumping unit including a sucker rod string and means to reciprocate said rod string to produce fluid from a subterranean location, the steps comprising:

a. generating a signal representative of a changing load in said unit as said rod string is reciprocated,

b. operating on said signal to produce an operating function representative of the rate of change of said signal, and

c. generating a monitor function in response to said operating function reaching a specified condition.

2. The method of claim **1** further comprising the step of, prior to step (b), clipping said load signal with respect to a peak amplitude reference value, and carrying out the operation of step (b) on said clipped load signal.

3. The method of claim 1 further comprising the step of amplitude discriminating said operating function to produce a residual function thereof, accumulating said residual function, and generating said monitor function in response to said accumulated residual function reaching a specified constraint.

4. The method of claim 1 wherein said load signal is differentiated to produce a derivative of said load signal as said operating function, amplitude discriminating said operating function with respect to a discrimination value to produce a residual of said operating function comprising a plurality of pulses characteristically proportional to the amplitude differentials between the corresponding peaks of said operating function and said discrimination value, integrating said residual function, and generating said monitor function in response to said integrated residual function reaching a specified constraint.

5. The method of claim 4 wherein said pulses are proportional in duration to said amplitude differentials.

6. The method of claim 1 further comprising:
comparing said load signal with an amplitude range having an upper amplitude limit and a lower amplitude limit, and
generating a monitor function in response to the amplitude of said load signal falling outside of said range.

7. The method of claim 1 further comprising:
amplitude discriminating said load signal with respect to a high amplitude discrimination value, and
generating a monitor function in response to said load signal failing to reach said value within a specified frequency condition.

8. The method of claim 7 further comprising the step of, prior to step (b) of claim 1, clipping said load signal with respect to a peak amplitude reference value which is less than said high amplitude discrimination value, and carrying out the operation of step (b) on said clipped load signal.

9. The method of claim 7 further comprising:
comparing said load signal with an amplitude range having an upper amplitude limit and a lower amplitude limit, said upper amplitude limit being greater than said high amplitude discrimination value, and
generating a monitor function in response to the amplitude of said load signal falling outside of said range.

10. In a system for use in monitoring the operation of a well pumping unit of the type having a rod string and means for reciprocating said rod string to operate a downhole pump, the combination comprising:
transducer means adapted to be connected to a well pumping unit of the type described for generating a signal representative of a changing load in said unit,
operator means responsive to said load signal for producing an operating function representative of the rate of change of said load signal, and
means responsive to said operating function for generating a monitor function upon said operating function reaching a specified condition.

11. The system of claim 10 further comprising:
discriminator means responsive to said load signal for amplitude discriminating said load signal with respect to a high amplitude discrimination value to produce a residual of said load signal, and
timing means responsive to the residual output signal from said discriminator means for generating a second monitor function upon said load signal failing to reach said high amplitude discrimination value within a specified frequency condition.

12. The system of claim 11 further comprising:
means responsive to said first-named monitor function for disabling the operation of said timing means to generate said second-named monitor function.

13. The system of claim 11 further comprising:
comparator means responsive to said load signal for generating a readout function upon the amplitude of said load signal falling outside of the upper and lower limits of an amplitude range encompassing said high amplitude discrimination value.

14. In a system for use in monitoring the operation of a well pumping unit of the type having a rod string and means for reciprocating said rod string to operate a downhole pump, the combination comprising:
transducer means adapted to be connected to a well pumping unit of the type described for generating a signal representative of load changes in said unit,
operator means responsive to said load signal for differentiating said load signal to produce an operating function which is a derivative of said load signal,
means for amplitude discriminating said operating function with respect to a specified discrimination value to produce a residual function comprised of a plurality of pulses characteristically proportional to the amplitude differentials between the corresponding peaks of said operating function and said discrimination value,
means responsive to the output from said amplitude discriminating means for integrating said residual function, and
means responsive to the output from said integrating means for generating a monitor function upon said output reaching a specified constraint.

15. The system of claim 14 wherein said pulses are proportional in duration to said amplitude differentials.

16. The system of claim 4 further comprising:
clipper means interposed between said transducer means and operating means for clipping said load signal with respect to a peak amplitude reference value whereby said operator means differentiates said clipped load signal.

17. The system of claim 16 further comprising:
second discriminator means responsive to said load signal for amplitude discriminating said load signal with respect to a high amplitude discrimination value to produce a residual of said load signal, and
timing means responsive to the residual output signal from said second amplitude discriminating means for generating a second monitor function upon said load signal failing to reach said high amplitude discrimination value within a specified frequency condition.

18. The system of claim 17 further comprising comparator means responsive to said load signal for generating a third monitor function upon the amplitude of said load signal falling outside of the upper and lower

limits of an amplitude range encompassing said high amplitude discrimination value.

19. In a system for monitoring the operation of a well pumping unit of the type having a rod string and means for reciprocating said rod string to operate a downhole pump, the improvement comprising:

transducer means connected to said well pumping unit for generating a signal representative of a changing load in said unit as said rod string is reciprocated,

operator means responsive to said load signal for producing an operating function representative of the rate of change of said load signal, and

means responsive to said operating function for generating a monitor function upon said operating function reaching a specified condition.

20. The system of claim **19** further comprising: discriminator means responsive to said load signal for amplitude discriminating said load signal with respect to a high amplitude discrimination value to produce a residual of said load signal, and

timing means responsive to the residual output signal from said discriminator means for generating a second monitor function upon said load signal failing to reach said high amplitude discrimination value within a specified frequency condition.

21. The system of claim **20** further comprising:

means responsive to said first-named monitor function for disabling the operation of said timing means to generate said second-named monitor function.

22. The system of claim **20** further comprising:

comparator means responsive to said load signal for generating a readout function upon the amplitude of said load signal falling outside of the upper and lower limits of an amplitude range encompassing said high amplitude discrimination value.

23. In a system for monitoring the operation of a well pumping unit of the type having a rod string and means for reciprocating said rod string to operate a downhole pump, the improvement comprising:

transducer means connected to said well pumping unit for generating a signal representative of load changes in said unit as said rod string is reciprocated,

operator means responsive to said load signal for differentiating said load signal to produce an operating function which is a derivative of said load signal,

means for amplitude discriminating said operating function with respect to a specified discrimination value to produce a residual function comprised of a plurality of pulses characteristically proportional to the amplitude differentials between the corresponding peaks of said operating function and said discrimination value,

means responsive to the output from said amplitude discriminating means for integrating said residual function, and

means responsive to the output from said integrating means for generating a monitor function upon said output reaching a specified constraint.

24. The system of claim **23** wherein said pulses are proportional in duration to said amplitude differentials.

25. The system of claim **23** further comprising:

clipper means interposed between said transducer means and operating means for clipping said load signal with respect to a peak amplitude reference value whereby said operator means differentiates said clipped load signal.

26. The system of claim **25** further comprising:

second discriminator means responsive to said load signal for amplitude discriminating said load signal with respect to a high amplitude discrimination value to produce a residual of said load signal, and

timing means responsive to the residual output signal from said second amplitude discriminating means for generating a second monitor function upon said load signal failing to reach said high amplitude discrimination value within a specified frequency condition.

27. The system of claim **26** further comprising comparator means responsive to said load signal for generating a third monitor function upon the amplitude of said load signal falling outside of the upper and lower limits of an amplitude range encompassing said high amplitude discrimination value.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,838,597 Dated October 1, 1974

Inventor(s) Richard C.Montgomery and Jacque R. Stoltz

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

Column 7, line 45, delete "circuit".

Column 8, line 6, "uniit" should be --unit--;
line 7, "donw" should be --down--;
line 8, "pujping" should be --pumping--.

Column 12, line 46 (claim 16, line 1), "The system of claim 4" should be --The system of claim 14--.

Signed and sealed this 3rd day of December 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents