Method and apparatus for controlling the operation of a prime mover of a pump jack apparatus. The apparatus comprises control circuitry and sensing means for measuring a change in the normal movement of the rod string on the downstroke so that when the fluid level within the borehole falls below the inlet of the pump means, the occurrence of fluid pounding causes a reaction in the rod string which is transferred into the walking beam of a pump jack. The sensing apparatus is mounted on the walking beam and measures this change in movement and provides a signal to the control circuitry which de-energizes the prime mover of the pump jack apparatus until the fluid level in the borehole has recovered.
1

PUMP-OFF CONTROL APPARATUS FOR A PUMP JACK

BACKGROUND OF THE INVENTION

Pump jack apparatus for recovering oil from an oil producing formation located downhole of a borehole takes on many different configurations and generally is comprised of a prime mover connected to a reduction gear box which moves a massive crank and counterweight so that a walking beam connected thereto by a pitman can move the rod string connected to the pump in a reciprocating and cyclic manner. In producing oil in this described manner, the prime objective is to lift a maximum amount of fluid at the lowest possible cost. In order to attain this goal the pump must be operated when the fluid level within the borehole is above the top of the pump and the well should therefore be shut-in whenever this fluid level is lowered therebelow, because the well will otherwise reach a pumped-off condition which is detrimental to the pump and rod string.

Occasionally the bottom hole pressure reaches a value to cause the formation to "flow off" as may be encountered during secondary recovery procedures such as water flooding, for example. In this instance, the pump will encounter an unbalanced condition which it heretofore had not experienced and accordingly, measuring current flow or torque output of the prime mover has been found to be unsatisfactory as a means of determining a true pump-off condition. In this instance the well will be shut in at a highly undesirable time because of the excess fluid present in the borehole awaiting to be produced.

Others in the present art have employed a geophone or a noise pick-up apparatus which usually is mounted to the Sampson post of the pump jack apparatus so that noise or vibration can be utilized as an indication of downhole conditions. It has been found that this type device will respond to extraneous noises such as loose bearings on the pitman arms, or ill-fitting pump bases, but most importantly the noise pick-up apparatus fails to distinguish between the vibration caused by "fluid pound" and the vibrations caused by "gas pound."

Gas pound is a phenomenon experienced when gas flows from the formation into the borehole annulus causing the pump to pound in a manner and pattern similar to that experienced with fluid pound conditions. The major difference between fluid and gas pound is that the latter is somewhat softer than the former; however, the noise or vibration detector usually cannot discern the difference.

Accordingly, it would be desirable to be able to measure the action of a pump jack apparatus in a simple and foolproof manner which would enable one to determine the instant that the bottom hole pump reached a true pump-off condition, and which furthermore distinguishes between gas pound and fluid pound so that the downhole pump can be operated continuously with the fluid level within the borehole being monitored so that the downhole pump, upon reaching a true pump-off condition, could be shut-in for a predetermined time dependent upon its previous history of operation.

SUMMARY OF THE INVENTION

This invention comprehends method and apparatus for de-energizing the prime mover of a pump jack app-
3,851,995

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a diagrammatical representation of pump jack apparatus which reciprocatingly drives a downhole pump, and wherein there is illustrated apparatus associated therewith which has been fabricated in accordance with the present invention;

FIG. 2 is a side elevational view of a control panel made in accordance with the present invention;

FIG. 3 is a side elevational view of mechanical and electrical circuit components made in accordance with the present invention;

FIGS. 4 and 6 are schematic diagrams of a circuit for use in conjunction with the apparatus disclosed in FIGS. 1–3; and,

FIG. 5 is a plot drawn by a dynamometer which illustrates one of the beneficial attributes of the present invention.

**DETAILED DESCRIPTION OF THE EMBODIMENTS**

In FIG. 1 there is disclosed pump jack apparatus having a base 10 upon which there upwardly depends a Sampson post 12 having a walking beam 14 journaled thereto. Prime mover 16 is illustrated herein as an electrical induction motor, although it equally well could be an internal combustion engine as will be appreciated later on in the disclosure. Gear reduction unit 18 is driven by the prime mover and imparts rotary motion into the crank and counterweights which are journaled to the reduction gear at shaft end 20. Cables 21 are attached to a horse head 22 in the usual manner so that a string or sucker rod can be attached at 23 and reciprocatory motion imparted into a bottom hole production pump located downhole within the wellhead 24 of a borehole.

Apparatus housed within enclosure 26 contains sensing means made in accordance with the present invention by which the prime mover is selectively energized and de-energized in accordance hereof. The box is attached by any suitable brackets 28 so that it can be mounted easily and quickly to the beam. Control box 30 is of usual design and contains circuit means therein which can be connected to a standard electrical power line so that the prime mover can be started and stopped by manual or automatic control as is known to those skilled in the art. Conduit means 32 connects control means 34, made in accordance with the present invention, to the controller 30 and to the sensor 26.

Looking now to the details of FIG. 2, wherein there is disclosed the before mentioned control box 34 having disposed therein various circuitry and electrical components seen disclosed in FIGS. 1, 3, and 4. As particularly disclosed in FIG. 2, an elapsed timer 35 is disposed adjacent to a trigger device 36, which includes a power supply. A downtimer 37 has the illustrated adjusting knob disposed thereon. Fuses 38 protect the ciruitry while pilot lights 39 show the operative configuration of the apparatus, as will be more fully explained later on. Switch 40 de-energizes the entire control apparatus while re-set push button 41 is disposed in ready access. Relays 42, 43, and 44 are mounted to the box, along with power regulator 45 and resistor 46. Power transformer 47 provides a proper power source while terminal block 48 facilitates connecting up the various conductors to the circuity.

Looking now to the details of FIG. 3, there is seen a second terminal block 49 to which there can be attached the various conductors contained within conduit 50. A first switch means 51 is pivotally mounted to be moved into a conducting configuration during each pump downstroke, while a second switch means 52 is mounted to be moved into a conducting configuration upon an abnormal movement of the rod string which is indicative of fluid pounding as will be better appreciated later on in this disclosure.

A third switch means 53, hereinafter referred to as a parted rod switch, is mounted at the upper portion of the box and is utilized to de-energize the prime mover whenever a rod string breaks. Solenoid 54 forms part of the rod parting apparatus as will be discussed in greater detail later on.

Looking again now to the details of the first switch means there is seen a journal 55 about which the entire switch assembly 51 is pivotally mounted by means of the spaced ears 56. U-shaped clamps 57 hold the glass vial 59 which encapsulates a blob of mercury 58 therewith. Wires 60 terminate within the vial and form spaced contacts which may be shorted together by the mercury. Legs 61 adjustably limit the angular disposition of the switch apparatus as it goes over-center.

The sensor apparatus for sensing the rate of change in movement of the rod string includes a resilient arm 62 mounted to the case, having a medial end portion attached to a wall by fastener means 63. Sensitivity adjustment means 64 has a curved distal end portion 65 which engages an intermediate marginal portion of the before mentioned rod 62, with the medial end portion mutually sharing fastener 63 with the before mentioned resilient rod. Adjustment 66 biases end portion 65 against resilient rod 62.

Magnet 67 is affixed to the distal end portion of the resilient rod 62 and is placed in close proximity to the magnetically actuated switch 52. The magnet is therefore resiliently mounted for limited movement relative to the switch 52.

Lever 68 of the parted rod sensor is affixed to magnet 69 with the face of the magnet being held by magnetic attraction in spaced relationship relative to plate member 70. Free end portion 71 of the rod adjustably contacts stop 72 which can be used to vary the air gap between elements 69 and 70. Journal 73 enables free end portion 71 of the rod to pivot thereabout. Plunger 74 is spaced from and underlies arm 68 while the before mentioned solenoid 54 extends the plunger therefrom when energized so that magnet 69 is reset or returned into the illustrated configuration seen in the drawing.

Looking now to the details of FIG. 4 wherein there is disclosed a source of current 5 connected to junction 75 with the parted rod switch 53 connecting relay switch element 42 to the current source when the switch is closed. Junctions 78 and 80 are connected to diode 79 and to relay switch element 43. Junction 80 connects the last two components to the before mentioned downtimer 37. Junction 81 is connected at 82 to the downtimer and also provides a source of current to the over-the-center switch 51. Fluid pound detector switch 52 is series connected with switch 51 and with the two resistors at 84 and 85 so that current flows from 81, 51, 52, 84, 85, and to junction 86 when the nor-
mally open switches are jointly moved to the closed or conducting position.

Resistor 87 is series connected to diode 88 which in turn is connected to the downstrum trigger input 89 while diode 90 connects junction 86 to the parallel connected capacitor 92 and to the normally closed time delay switch means 44 which opens 30 seconds after restart. Junctions 83, 93, and 94 are grounded with the difference in potential from 75 to 94 being approximately 12 volts D.C. Normally closed switches 243 and 343 are moved to the opened position by solenoid 43 while normally closed switches 242 and 342 respectively are moved to the closed and opened position respectively by solenoid 42.

Looking now to the details of FIG. 5, there is disclosed a plot illustrating the results of a dynamometer apparatus having been connected at 23, for example, in FIG. 1. As seen in FIG. 5, the x axis represents time or rod stroke while the y axis represents force or rod string weight. Curve 95 and 96 represent the downstroke and the upstroke respectively, while sides 97 and 98 represent the increment of time in which the tension in the rod changes as the direction in rod travel reverses. The plurality of curves at 98 to 99 represent a progressive loss in lifting force due to fluid pounding. Accordingly, beginning with curve 95 it will be seen that the rod is on the downstroke until the rod reverses itself at 197 and commences to lift production fluid to the surface of the ground. Curve portion 96 represents the travel of the rod as it lifts the fluid, and at 198 the rod reverses itself and starts on its downstroke. The curves between 98' and 99 represent various increasing degrees of fluid pounding which transmits a force into the rod string and walking beam.

FIG. 6 discloses one form of pilot or control circuitry 234 which can be employed at 30 for control of motor 16. A 440v. A.C. 60 3 φ source of current is usually employed as a source of current for a 30 horsepower high slip electric pump jack motor, and accordingly the 440v. source is stepped down to 115v. 1 φ at 101 and 102 so as to provide a suitable source of pilot control current at 30 as is known to those skilled in the art. Numeral 108 indicates the pilot current source which, in accordance with the prior art, usually will be directly connected to the 1 φ 115v. supply at 101 and 102. Hence the present invention can be adapted to the circuitry of a conventional pump jack system by connecting the prior art pilot circuit at 108 and by interposing the present control circuitry at 101 and 102.

The parted rod and fluid pound switches are arranged to interrupt current flow to the conventional pilot circuit 108. Should any malfunction of the circuitry 134 or 234 of the invention occur, the switches 243, 342, 343 will assume the closed position and the pump jack will be returned to its conventional operational configuration.

The details of one form of the downstrum 37 which can be used in the present invention is found in a Signetics NE 555 integrated circuit. This circuitry, known to those skilled in the art, is comprised of a monolithic timing circuit which is a highly stable controller capable of producing accurate time delays, or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For a stable operation as an oscillator, the free running frequency and the duty cycle are both accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output structure can source or sink up to 200mA or drive TTL circuits.

In operation, the sensor 26 is removably affixed at 28 to the walking beam with the conductors 50 being led through a suitable conduit 32 to the control box 34 and to the motor controller 30. The controller 30 is energized by closing switch 140 while the control circuit at 34 is energized by means of switch 40. As the apparatus commences to produce fluid, the first few cycles may cause the sensor to be actuated due to the presence of extraneous noises such as may be caused by debris in the fluid column. Accordingly, the thirty second time delay relay 44 will prevent this signal from being recorded or stored at 92. After a suitable time delay the apparatus will be placed in the operational configuration with current flowing from source S to the over-the-center mercury switch 51, where it is available at the sensor element 52 should fluid pounding be incurred.

As the apparatus rides in an oscillating manner with the walking beam, the over-the-center mercury switch is moved into the conducting configuration of FIG. 3 each downstroke of the sucker rod. This action causes the mercury 58 to short the contacts thereof so that should switch 52 close, a pulse of current will be stored within the capacitor 92. As the sucker rod upstrokes, over-the-center mercury switch 59 reverses the illustrated position seen at 51 so that the action of switch 52 is of no consequence during this portion of the pumping cycle.

Often a high fluid level will be present in the casing annulus upon start-up, causing gas ponding to occur due to aerated or foaming action from the occurrence of a flow-off condition which occurred during the downtime, for example. Therefore, the adjustment 66 can be used to further rigidify arm 62 so as to prevent sufficient movement of magnet 67 to occur which otherwise would close switch 52. This expedient enables the pump to continue to operate down to a pump-off condition illustrated at 98' which will be caused by fluid pounding. Stated differently, the apparatus is adjusted to “slide over” the gas pound disturbance. When fluid ponding first occurs, magnet 67 moves a sufficient amount to cause switch 52 to close. Closure of switch 52 causes current to flow to junction 91 where the pulse is stored in capacitor 92. Each stored pulse further raises the available voltage level at junction 91 and 89. When the threshold voltage of downstrum 37 is reached, current will flow through the resistor at 87 and trigger the downstrum 37, so that current flows from 80 to 94 thereby energizing solenoid 43 which opens contacts 243 and 343, the latter of which are series connected to controller 30 so that the pilot circuitry thereof de-energizes the prime mover 16. Hence, the downstrum 37 has a circuit component connected from 82 to 83 which causes the contacts of solenoid 43 to remain in the open condition for a length of time based on the production history of the well to thereby enable the fluid head thereof to raise to a level which warrants restart of the prime mover. When the element 37 times out, switches 243 and 343 are closed by de-energization of solenoid 43. Contact 243 energizes heater elements 44, however, the contact thereof requires about thirty seconds time delay prior to opening. Hence, time delay switch 44 effectively shorts capaci-
3,851,995

tor 92 for the equivalent of several pump strokes, and thereafter returns the circuitry to the operating configuration so that the cycle can be repeated.

The apparatus preferably is provided with 12 volts at S so that the battery of an internal combustion engine can be used as a power source with the contacts of solenoids 42 and 43 being utilized to disengage a clutch means or to interrupt the ignition circuitry of the engine.

Should the sucker rod part, the resultant reaction affected upon the walking beam is of a sufficient magnitude to cause the magnetic attraction between magnet 69 and plate 70 to be overcome, thereby pivoting the magnet into close proximity of magnetically actuated N.O. switch 53, causing current flow from 75, 53, 42, to 94. This causes the switch 342 to assume the open position, interrupting the pilot circuit current flow and shutting in the well. At the same time, switch 242 is moved to the closed position to energize the light 39'. Switch 41 resets the member 69 by energizing solenoid 54. Pilot light 39 indicates the presence of operating current. Pilot light 39' indicates that a rod has parted.

The lapsed timer is a recording instrument which records the accumulated time the pump jack is in operation.

It will be appreciated that the sensor of the pump-off control works on the principle that two objects 52, 67 moving in the same direction at the same relative velocity, when subjected to a change in velocity, will move relative to one another if one of the objects are suspended in a manner to enable it to move with unbound motion relative to the other object. The relative motion between the two objects is used to produce the signal of the pump-off control of the present invention.

I claim:

1. A control system for the control of a prime mover of an oil well pump jack apparatus which drives a downhole pump by means of a rod string comprising:

control means by which the prime mover is selectively energized and de-energized;
first switch means mounted to be moved into a conducting configuration during the pump downstroke;
second switch means mounted to be moved into a conducting configuration upon an abnormal movement of the rod string indicative of fluid pounding;
circuit means connected to said first and second switch means and to said control means for counting the number of times said second switch means is closed and for causing said control means to de-energize said prime mover after said second switch means has been moved to the closed position a plurality of times;
a third switch means, said third switch means being a magnetically actuated switch, a magnet for actuating the last said switch when the magnet is moved into close proximity thereof, said magnet being magnetically attached to structure mounted to said pump jack means so that should a rod string break, the magnet will be forced to move relative to said structure and into proximity of said third switch means, thereby actuating said third switch means; and,
circuit means by which actuation of said third switch means causes said prime mover to be de-energized.

2. In an oil well pump jack apparatus having a prime mover which drives a downhole pump by means of a rod string, wherein the prime mover has a control means by which the prime mover is selectively energized and de-energized; an improved control system for said prime mover comprising:

first switch means mounted to be moved into a conducting configuration during the pump downstroke so that cyclic movement of the pump jack causes the switch means to assume a conducting configuration on the downstroke and a non-conducting configuration on the upstroke;
second switch means mounted to be moved into a conducting configuration upon an abnormal movement of the rod string indicative of fluid pounding;
a source of current; said first switch means being series connected to said second switch means and to the source of current;
circuit means forming an electrical pulse storage apparatus for counting the number of times said second switch means is closed; a solenoid actuated switch means having the switch thereof connected to cause said control means to de-energize said prime mover when the solenoid is actuated, said solenoid actuated switch means having the solenoid thereof connected to said circuit means so that when said second switch means has been moved to the closed position a plurality of times said electrical pulse storage apparatus causes the solenoid to be energized, thereby causing the prime mover to be de-energized.

3. A control system for the control of a prime mover of an oil well pump jack apparatus which drives a downhole pump by means of a rod string comprising:

control means by which the prime mover is selectively energized and de-energized;
first switch means, said first switch means being mounted for movement to the pump jack so that cyclic movement of the pump jack causes the switch means to be moved into a conducting configuration during the pump downstroke and moved into a non-conducting configuration during the pump upstroke;
second switch means series connected to said first switch means and mounted to be moved into a conducting configuration upon an abnormal movement of the rod string indicative of fluid pounding;
circuit means including an electrical pulse storage apparatus connected to said first and second switch means for counting the number of times said second switch means is closed and for causing said control means to de-energize said prime mover after said second switch means has been moved to the closed position a plurality of times.
4. The control system of claim 3 wherein said second switch means is a magnetically actuated switch;
a magnet means resiliently mounted for movement to said pump jack apparatus; said magnet being disposed adjacent to but spaced from said second switch means; said magnet and said second switch means being mounted for movement in relation-
ship with said rod string so that when said magnet is moved relative to said second switch means, said second switch means is moved into the stated conducting configuration.

5. The control system of claim 3 wherein there is further included a third switch means; circuit means by which said third switch means is connected to de-energize said prime mover when moved from a normal to an alternate position.

6. The control system of claim 3 wherein said third switch means is a magnetically actuated switch, a magnet for actuating said switch when moved into close proximity thereof, said magnet being magnetically attached to structure mounted to said pump jack means so that should a rod string break the magnet will be forced to move relative to the structure and into proximity of said third switch thereby de-energizing said prime mover.

* * * * *