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OIL WELL PUMP CONTROL SYSTEM

Filed Oct. 22, 1965

2 Sheets-Sheet 1

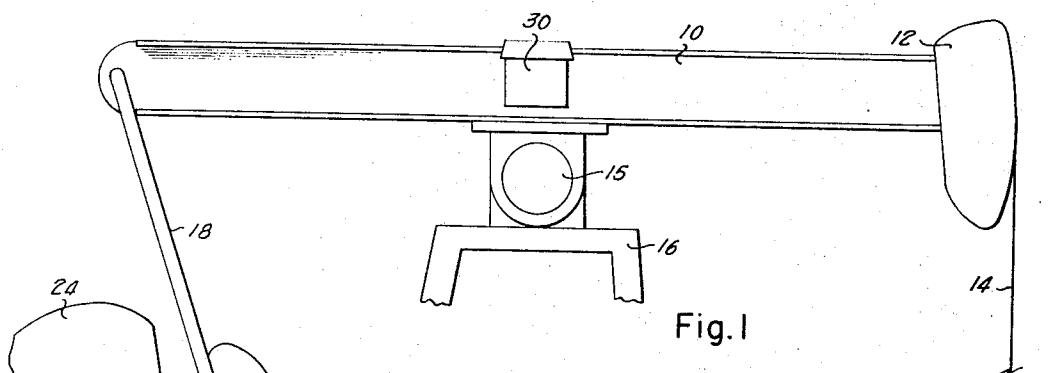


Fig. 1

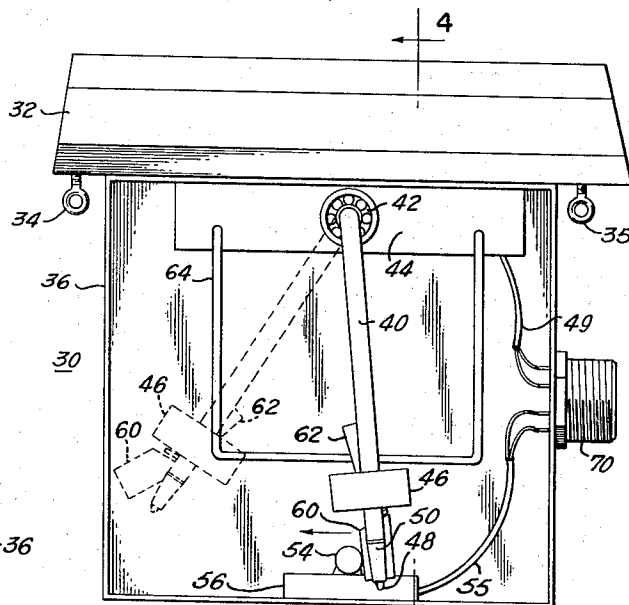


Fig. 3

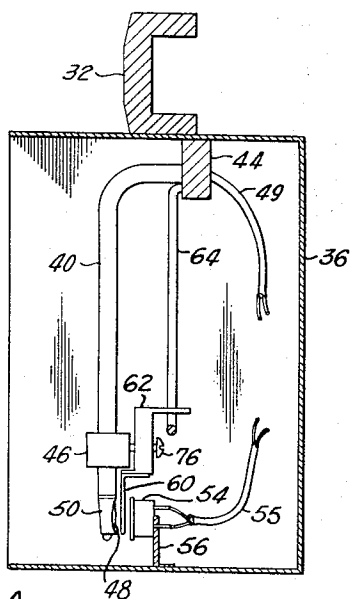


Fig. 4

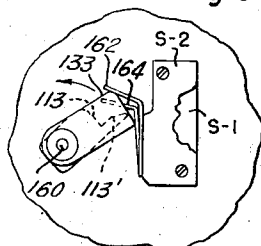


Fig. 6-A

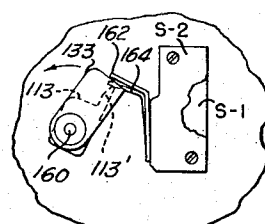


Fig. 6-B

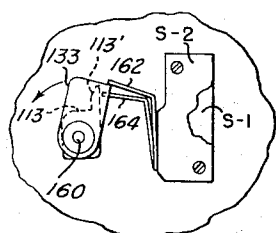


Fig. 6-C

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2 Sheets-Sheet 2

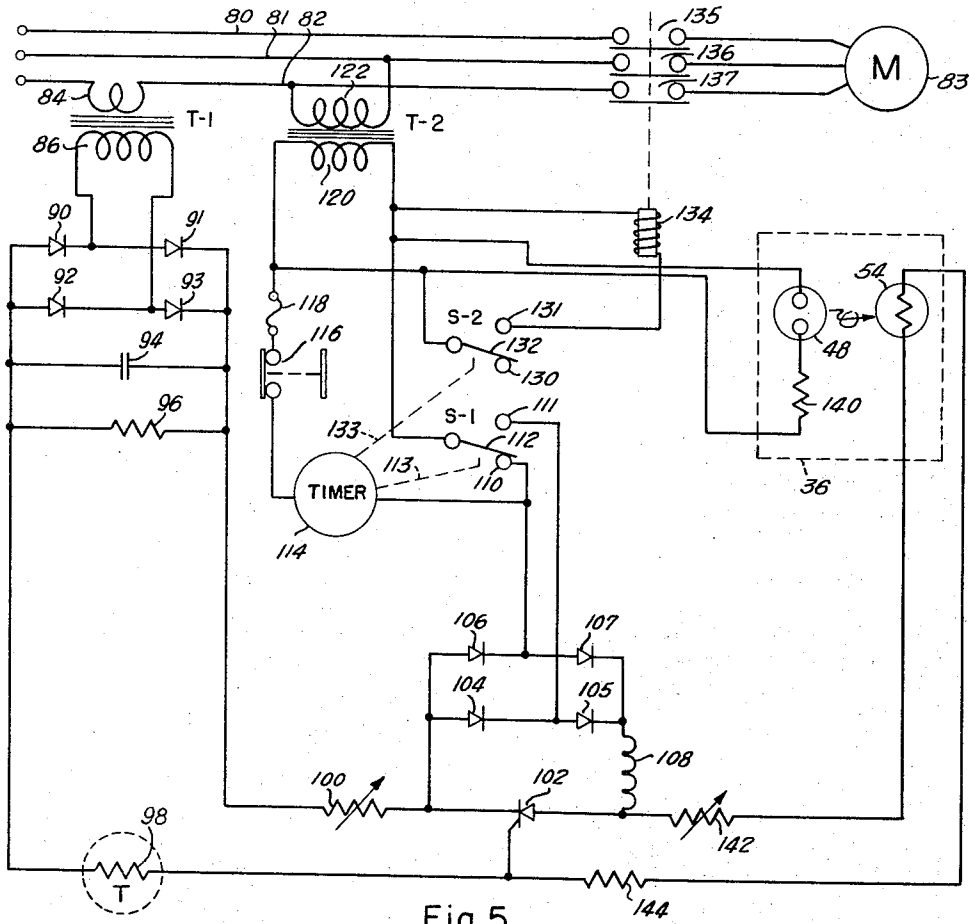


Fig. 5

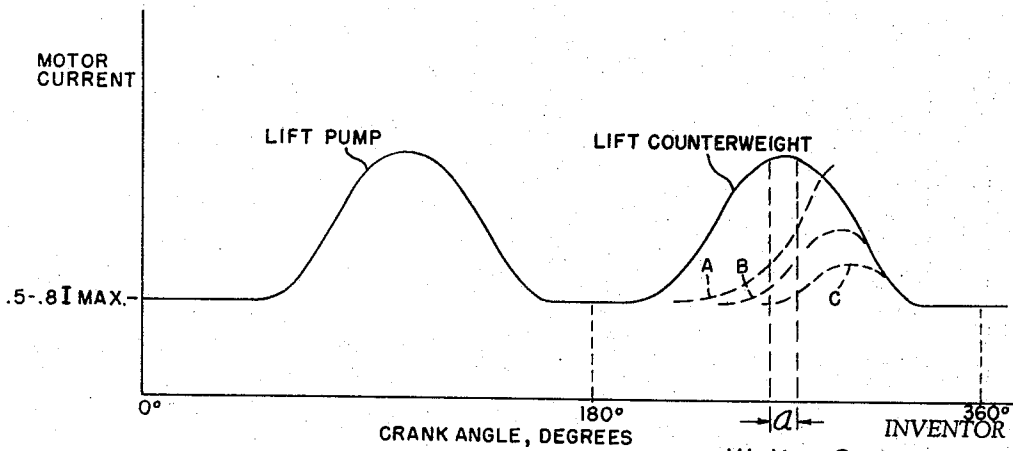


Fig. 2

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OIL WELL PUMP CONTROL SYSTEM

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ABSTRACT OF THE DISCLOSURE

A control system for a well pump, and more particularly, a system for controlling the operation of an electric motor used to drive a pump as a function of pumping characteristics which affect the electric current drawn by the electric motor is described. A first signal is produced as a function of the pump arm position, and a second signal is produced as a function of the pump motor current and compared to the first signal to control the operation of the pump.

It is common practice to operate pumps continuously on oil well installations even though the capacity of the pump may exceed the rate of flow of oil into the well bore. Moreover, a large percentage of the wells being pumped do not have a flow rate capacity which is sufficient to utilize the full capacity of the pump, wherein many such wells have been pumped for some time and are of low capacity. The continuous pumping of these wells, however, is uneconomical in that a considerable amount of electrical energy is wasted and in that wear of the pump assembly is significant. Wear of the pumping machinery results not only from operating the pump when it should be turned off but from vibration incurred when "fluid pound" occurs, wherein the term "fluid pound" is used to denote a downhole condition of the oil level within the well casing.

"Fluid pound" occurs when the fluid within the well cannot fill the well bore at a rate as fast as the traveling valve moves upward on the pump upstroke. Thus when the traveling valve within the well bore moves downward on the downstroke, it will travel through a distance where there is no fluid, but will eventually strike or "pound" the surface of the fluid. The greatest force experienced on this impact is when the traveling valve is traveling at its greatest downward speed. Thus less "fluid pound" will be experienced when the fluid level is sufficiently below the traveling valve so that when the impact occurs, the traveling valve is at or near the end of its downward stroke, and thus is traveling at a lower speed. A fluid level this low, however, indicates poor production.

The ideal pumping condition is to pump only for an optimum period of time when the fluid flow rate within the well is sufficient to match or approximate the pump capacity, thus eliminating the wasting of electrical energy and wear on the machinery when the pump should be turned off. Moreover, it has been found that a good indication of when the pump should be shut down to achieve this optimum condition is when "fluid pound" occurs to a particular degree. However, it is quite impractical to control the running and stopping of the pump manually, and attempts to provide automatic controls have not met with any degree of success because of the basic impracticality of designs.

The provision of an automatic control is based upon the fact that "fluid pound" occurs only on the downstroke of the pump into the well casing. It is also known that the magnitude of the current drawn by the electric motor driving the pump varies in a particular manner as a function of the angular position of the pump crank and that this current magnitude varies as a function of the

2

degree of "fluid pound" occurring during the downstroke. Thus simultaneous measurements of the current magnitude drawn by the motor and the angular position of the pump crank at which "fluid pound" will occur is necessary in order to provide a suitable automatic control.

The provision of means for measuring the proper angular position of the pump crank presents problems in that the angular position at which "fluid pound" occurs varies from well to well, so that the current drawn by the motor, which is indicative of this condition, varies from well to well as a function of the crank angle. It has been found impractical, however, to make fine adjustments of the means, which is usually mechanical, for measuring the angular position of the pump crank, and thus some other scheme must be used to insure the coincidence of the two measurements of crank angle and motor current.

It is an object of this invention to provide an automatic pump control system of the type discussed above wherein the measurement of the motor current magnitude indicating the condition of "fluid pound" always coincides with the measurement of the proper angular position of the pump crank, wherein the problem of determining and maintaining this coincidence from well to well is eliminated. In accordance with this object, the system of the invention averages to a degree the current magnitude measured over the downstroke of the pump, and thus provides a current measurement during the time "fluid pound" may occur which coincides with a greater angular increment of the pump crank. This greatly reduces the criticality of making the current measurement and crank angle measurement coincide. This does not reduce the sensitivity of the system but, on the contrary, allows for a much finer adjustment to achieve the exact control desired.

Another object is to provide a much simplified automatic control which is more accurate, has few component parts, and is not subject to failure or mechanical wear. To achieve this, the combination of optical and electronic means are used in conjunction with a pendulum system attached to the rocking arm of the pump to measure the angular position of the rocking beam or crank angle equivalent. A pendulum is subject to very little wear, and the system produces an electrical output signal as the pendulum passes through a predetermined range of its travel as determined by the angular position of the rocking arm, wherein the signal is generated by means of a lamp and light detector. The remainder of the control system is essentially electrical, which utilizes solid state devices for further simplification and assurance against failure.

It is also an object to provide means for measuring the angular position of the pump crank which requires no stationary reference point on the pump assembly itself. This gives a much greater choice as to where this means can be located or attached to the pump assembly, and also makes it possible to completely seal the means as a unit to protect it from weather conditions. In accordance therewith, the invention uses gravity actuated means, such as the pendulum assembly mentioned above, which can be attached to the rocking arm of the pump to be actuated thereby, whereby it is not required to use a stationary reference to measure this angular position in relation thereto.

There are other objects, features and advantages that will be come apparent from the following detailed description of a preferred embodiment of the invention when taken in conjunction with the appended claims and the attached drawing wherein like reference numerals refer to like parts throughout the several figures, and in which:

FIGURE 1 is a side elevational view of part of a pumping system showing the position of attachment to the rocking arm of the pump of means for measuring the angular position of the crank angle;

FIGURE 2 is a graphical representation of the motor current as a function of the angular position of the pump crank;

FIGURE 3 is a front elevational view of a gravity actuated pendulum system, utilizing both optical and electronic means, for attachment to the rocking arm for measuring the angular position of the pump crank;

FIGURE 4 is a side elevational view, in section, of the pendulum system taken through section lines 4—4 of FIGURE 3;

FIGURE 5 is an electrical schematic diagram of the control system of the invention; and

FIGURES 6A—6C are fragmentary views of a timer and corresponding switches used in the control system.

Referring now to FIGURE 1, the well pump comprises a rocking beam 10 for actuating a sucker rod 14 connected to a horsehead 12 attached to one end of the rocking beam. The rocking beam is mounted on a support or base 16 through a bearing or axle 15 for reciprocation about the bearing 15. The rocking beam is driven through a connecting rod 18 attached to the other end thereof. The connecting rod is connected to a counterbalance 20, the latter of which is caused to rotate in either a clockwise or counterclockwise direction. For purposes of the following description, counterbalance 20 is shown to be rotating in a counterclockwise direction as viewed in FIGURE 1, wherein the counterbalance is supported on an axle through a bearing support 22 and is driven by a conventional three-phase electric pump motor (not shown) through a conventional gear drive 24.

Sucker rod 14 extends down into the well hole and is connected to a conventional reciprocating valve assembly for pumping oil out through the well head as the sucker rod and valve assembly are caused to reciprocate up and down within the well hole. Oil is pumped out of the well on the upstroke of the pump, or when the horsehead is being raised. This occurs when the counterbalance is traveling downward. Moreover, fluid will also be flowing into the well casing on this upstroke as a result of the sucking action of the traveling valve and the natural downhole pressure. However, should the rate at which the pump assembly can remove fluid from the well exceed the rate which the fluid can refill the well casing, the well casing will not be refilled to the extent that it should, so that when the counterbalance is being raised to lower the horsehead and sucker rod, the traveling valve will strike the top of the fluid level and cause severe vibration.

Should the rate at which fluid can refill the well casing drop below the rate at which the pump can remove the fluid from the well, a condition known as "fluid pound" will exist, wherein the valve assembly within the well casing will strike against the surface of the fluid. This occurs when the fluid level is below the valve assembly and the sucker rod and pump assembly are going back into the hole. When this condition exists, the pump assembly is subjected to vibration and wear, while at the same time a much lower production will be achieved. Moreover, the cost of the electrical power required to run the pump assembly cannot be justified in view of the reduced production achieved.

It is known that when the condition of "fluid pound" exists, or when the fluid within the well casing cannot refill the casing at a sufficient rate to match the pumping capability of the pump assembly, the electrical current drawn by the pump motor will vary accordingly. Referring to FIGURE 2, there is shown a graphical representation of the current drawn by the pump motor as a function of the angular position of the rocking beam, or the position of the crank angle (which is the same or equivalent), the latter being the same as the angular position of the counterweight 20. During the 180 degrees rotation of the

counterbalance when it is traveling from its top most position to its lower most position to lift the horsehead and pump assembly, the current drawn by the pump motor will increase accordingly as shown in FIGURE 2 and then decrease as the counterbalance approaches its lower most position. As the counterbalance travels from its lower most position to its top most position to drive the horsehead downward and the sucker rod into the well casing, the motor current will vary in a similar fashion if the rate at which the fluid refills the well casing is sufficiently great. Should the condition of "fluid pound" exist when the counterweight is being lifted to drive the pump downward into the well casing, less current will be drawn by the pump motor as determined by the rate of fluid refill within the well casing. These proportionately smaller currents are illustrated by curves A, B and C in FIGURE 2. It will be noted that the reduced current drawn by the motor will exist only during the time that the counterweight is being lifted to drive the horsehead downward. Thus by measuring the current drawn by the pump motor during this particular 180 degree rotation of the counterweight, the condition of "fluid pound" can be detected, and turning off the pump motor to stop the pump at this time will reduce the wear on the pump assembly, in addition to eliminating the cost of running the pump assembly until the fluid can sufficiently refill the well casing. When there has been a sufficient refill, the motor is turned back on to continue the pumping action.

Curve A of FIGURE 2 represents the larger degree of "fluid pound," curve B proportionately less and curve C the least for the curves shown. Thus the smaller the current, the less "fluid pound." This is because the pump is traveling faster when it strikes the fluid level in curve A, and thus strikes the fluid at a higher level within the casing when the angular velocity of the crank angle is greater. As a consequence, the traveling valve must be pushed through a greater distance of fluid within the casing on the downstroke, and thus the pump motor experiences a greater load and draws more current. However, this current is less than when "fluid pound" is non-existent. Curves B and C represent proportionately less "fluid pound" and less load on the pump motor, although these curves are also indicative of proportionately less production capability.

As previously noted, the invention utilizes means for measuring the position of the rocking beam during the 180 degree rotation of the counterbalance when a measurement of the current drawn by the pump motor will indicate "fluid pound," means for simultaneously measuring the motor current during this particular movement of the rocking beam or counterbalance, and means for comparing the two. An electronic circuit is then used to automatically control the operation of the pump and respond to these two measurements. Referring to FIGURES 1, 3 and 4, the means for detecting the angular position of the rocking beam, counterbalance or pump crank will be described. The preferred means for detecting this angular position is a pendulum arrangement which is situated within a housing 30 securely attached to the rocking beam, and in more particular, this housing and pendulum assembly is attached to the rocking beam directly over the fulcrum point of bearing axle 15. FIGURE 3 is a front elevational view of the pendulum assembly supported within housing 30 with the front plate of the housing removed. An elongated bracket 32 is attached to the top of housing 36 with tightening screws 34 and 35 passing through the bottom to secure the entire assembly to a conventional I beam, which is the rocking beam of the pump. Referring to both FIGURE 3 and FIGURE 4, wherein FIGURE 4 is a side elevational view, in section, taken through lines 4—4 of FIGURE 3, a rigid pendulum arm 40 is supported for rotation within a bearing assembly 42 mounted within a rigid support member 44, the latter being attached to the top interior wall of housing 36. Attached to the lower end of the pendulum arm is a

weight 46 to provide the inertia for the pendulum. A lamp 48 is attached to the bottom of the pendulum arm and supplied by electrical power through leads 49 passing through the interior of the pendulum arm. The lamp is preferably one having a long lifetime and which can be operated continually, wherein a neon lamp is suitable for this purpose. A light shield 50 is provided about lamp 48 but defines an opening in the rear thereof through which light can pass as shown more clearly in FIGURE 4. A light detector 54, such as any conventional photoelectric cell, is mounted on a bracket 56 so that the photocell is in optical alignment with lamp 48 when the pendulum lamp is within a range of angular positions with respect to the photocell, wherein the latter responds electrically to the lamp within this range. Electrical connections are made to the detector 54 through leads 55, with leads 49 and 55 being connected to an electrical connector 70 for being connected to an electrical circuit exterior to housing 36. When the light from lamp 48 strikes detector 54 as the pendulum passes through its lowest point, an electrical pulse will be produced by the detector, which pulse is an indication of the position of the rocking beam or counterbalance when it is desired to measure current drawn by the pump motor.

Since the angular position of the rocking beam or counterbalance is to be detected or measured only when the counterbalance is being raised to drive the horsehead downward, provision must be made so that a pulse is produced by detector 54 only as the pendulum passes through its lowest point as it swings in one direction but not the other. The point of coincidence of the lamp and photocell may not be at the lowest point of the pendulum path, wherein the photocell may be displaced laterally as a fine adjustment to correspond to the characteristics of a particular pump and well. The angular position to be detected corresponds to a clockwise rotation of the pendulum assembly as viewed from FIGURE 3, but when the pendulum is rotated in a counterwise direction as the horsehead of the pump assembly is being raised, the pendulum will also pass through its lowest point. To eliminate an electrical pulse from being generated by the detector in the latter condition, a shield 60 is provided between the lamp and the detector which blocks the light as the pendulum moves from right to left as shown in FIGURE 3. The shield comprises a plate 60 rigidly attached to an actuating arm 62, the latter of which is rotatably attached to the rear of weight 46 by means of any suitable screw or bearing 76, as shown in FIGURE 4. A U-shaped member 64 is attached at its upper ends to support 44 and extends downward adjacent weight 46 for engaging actuating member 62 to cause it to rotate about bearing 76 as the pendulum moves to its extreme positions. As the entire pendulum assembly is rotated in a counterclockwise direction as shown in FIGURE 3 so that the pendulum itself moves from right to left, the U-shaped member 64 acts as a stop to limit the angular position of the pendulum by engaging actuating member 62. This causes actuating member 62 to rotate in a clockwise direction so that the light shield 60 is rotated out of coincidence with lamp 48. The angular position of shield 60 is limited by the bottom of the actuating member 62 coming to rest on the bottom of weight 46. As the entire pendulum assembly is rotated in a clockwise direction to cause the pendulum to move from left to right, lamp 48 will pass by detector 54 with the shield 60 being displaced angularly with respect to the lamp. At this time, light from lamp 48 is directed on the detector to produce an electrical pulse. As the pendulum continues to move from left to right, actuating member 62 engages the other side of the U-shaped member and causes the shield to again be positioned in front of the lamp, wherein the bottom of actuating member 62 acts to limit the angular position of the shield by again coming to rest on the bottom of weight 46. In this instance, the furthestmost position

of shield 60 will be in direct alignment with lamp 48, so that as the pendulum moves from right to left the shield blocks the light from detector 54 so that no electrical pulse will be produced. Therefore, an electrical pulse is produced each time the horsehead attached to the rocking beam is going down, but no electrical pulse is produced when the horsehead is raised. Referring again to FIGURE 2, the electrical pulse is produced during an interval which corresponds to an increment of angular movement of the rocking beam during the lifting of the counterweight or lowering of the horsehead. As the pendulum passes through its lowermost point at substantially the same time the rocking beam is horizontal, it will be seen that the electrical pulse is produced at approximately halfway through the downstroke of the horsehead. It has been found that producing the pulse at this time, at the same time which a measurement of the current drawn by the pump motor is also being made, gives the best indication of when "fluid pound" and low production actually exists.

From the foregoing discussion, it will be seen that the pendulum system comprises a self contained unit that is gravity actuated and which requires no mechanical or other connection to a stationary reference point on the pump assembly for the measurement of angular position. Thus the unit can be completely sealed against all weather conditions and is subject to very little wear, in addition to which a wide range of locations of attachment on the rocking arm can be used.

An electrical schematic diagram of the pump control of the invention is shown in FIGURE 5, which includes the electrical schematic diagram of lamp 48 and detector 54 associated with the circuit. A conventional three-phase electrical pump motor 83 is supplied through lines 80, 81 and 82 through contactors 135, 136 and 137, respectively. These contacts are actuated by solenoid 134 coupled thereto, whereby these contactors are in the closed position only when current is passed through solenoid 134. A first transformer T-1 is connected in series with one of the power lines 82 by means of a current winding 84. The secondary 86 of the transformer is connected to the input of a full wave rectifier bridge comprising diodes 90, 91, 92 and 93, with a capacity 94 and resistor 96 connected in parallel across the output of the bridge. It will be apparent that the voltage output of the bridge connected to transformer T-1 is proportional to the current drawn by motor 83 as detected by current winding 84. Although a current of 60 cycles per second is used to supply the pump motor, capacitor 94 essentially integrates this current so that the voltage at the output of the bridge follows very nearly, if not exactly, the curve for the motor current shown in FIGURE 2. Resistor 96 is provided so that capacitor 94 can discharge in order to follow the curve of FIGURE 2. The positive side of this bridge is connected to the cathode of a power switch 102, which is preferably a semiconductor controlled rectifier, through a variable resistor 100, with the negative side of the bridge being connected to the gate of the controlled rectifier through thermistor 98. A supply voltage is supplied to the controlled rectifier 102 through another full wave rectifier bridge comprising diodes 104, 105, 106 and 107, whereby the input of this rectifier bridge is supplied from the line voltage connected to the motor as will be described later. However, it will be noted that the polarity of voltage applied across the controlled rectifier is such as to forward bias the rectifier, so that with a sufficient current gating signal, the controlled rectifier will be caused to switch from its high impedance state to its low impedance state. The two output leads from detector 54 contained within housing 36 are connected between the anode and gate of the controlled rectifier through a variable resistor 142 and resistor 144, respectively. Because photocell 54 is referenced to the positive side of the rectifier bridge that includes diode 105, the signal

supplied to the gate of the controlled rectifier will be of a positive polarity. Thus the controlled rectifier can be switched to its low impedance state only when the positive voltage through photocell 54 overcomes the negative voltage supplied to the gate through current transformer T-1 by an amount to equal or exceed the turn on current, which must be positive. The circuit is adjusted through variable resistors 100 and 142 so that the controlled rectifier cannot be turned on while the current drawn by the motor exceeds that indicated by "fluid pound," but where the current pulse from the photocell is sufficient to turn on the controlled rectifier when the current drawn by the motor is reduced in magnitude, as shown by curves A, B and C of FIGURE 2, to indicate "fluid pound."

It is now apparent that the gate electrode of the controlled rectifier has applied thereto a voltage through current transformer T-1 and a rectifier bridge, wherein this voltage is proportional to the current drawn by the motor. It is also apparent that the signal for switching the controlled rectifier from its non-conductive state to its conductive state is derived from detector 54 in the form of a current pulse. When the motor is running and the current drawn thereby is sufficient to indicate that "fluid pound" does not exist, the voltage applied to the controlled rectifier is such that a pulse from detector 54 cannot switch the controlled rectifier to the low impedance state. Although voltage proportional to the motor current is applied to the controlled rectifier gate through current transformer T-1 at all times, a current pulse for turning on the controlled rectifier is applied to the gate only during the time that the counterbalance is being lifted and the horsehead lowered, or only when the current drawn by the motor will vary when "fluid pound" exists.

Another voltage transformer T-2 is connected at the primary 122 thereof across lines 81 and 82, with the secondary 120 of the transformer being connected to the input of the full wave bridge that supplies the controlled rectifier. The secondary 120 is connected to this bridge through a fuse 118, a reset switch 116, a timer 114 and through switch S-1, all of which will be described below. Lamp 48 is also supplied by line voltage by means of the secondary 120 of transformer T-2 through resistor 140. The solenoid 134 for operating contacts 135, 136 and 137 is supplied through line voltage by means of secondary 120 of transformer T-2 through another switch S-2.

The operation of the circuit will now be described, with the assumption being made that the motor is turned off and not running. The normal positions of contactors 112 and 132 of switches S-1 and S-2 are in engagement with poles 110 and 130 of switches S-1 and S-2, respectively, or in the down position as shown in FIGURE 5. Similarly, the normal position of contactors 135, 136 and 137 in lines 80, 81 and 82, respectively, are open, or in the down position as shown in the drawing and as previously noted. Under these conditions with contactor 112 of switch S-1 in engagement with pole 110, the timer is supplied directly from line voltage through transformer T-2. It will be noted that since pole 111 of switch S-1 is open, no supply voltage is supplied to the controlled rectifier 102. Moreover, there is no actuating current through pole 131 of switch S-2 to cause solenoid 134 to close the contactors 135, 136 and 137 to start or operate the motor. With the timer being supplied directly from line voltage, the timer is running and requires a predetermined period of time, depending on its particular position, before it will actuate switches S-1 and S-2 through mechanical connections 113 and 133, respectively, all as will be described below. After the timer has run for a predetermined period of time so that mechanical connection 133 is actuated, it will close switch S-2, or move contactor 132 out of engagement with pole 130 and into engagement with pole 131, thus supplying a

current through solenoid 134 from line voltage to close contactors 135, 136 and 137. The motor will then be started to initiate pumping action. The timer 114 continues to run during this time, and after an interval of time, preferably about 40 seconds, mechanical connection 113 of the timer will actuate switch S-1, or move contactor 112 out of engagement with pole 110 into engagement with pole 111. When this occurs, a supply voltage will be applied across controlled rectifier 102 so current for operating the timer must now be supplied through the controlled rectifier in order for it to continue to run. If the current drawn by the motor is of sufficient magnitude at this time so that there is no indication of "fluid pound," controlled rectifier 102 will not be switched to its low impedance state but will remain in the high impedance state. In this event, the controlled rectifier acts as an open circuit with all of the line voltage through transformer T-2 being established across the controlled rectifier. Thus no current will flow through the timer and it will cease to run. The circuit will remain in this condition for as long as the motor draws a sufficient amount of current which is in excess of that which is an indication of "fluid pound."

Should "fluid pound" exist when switch S-1 is closed and moved upward by the timer, or should "fluid pound" occur at any time thereafter when the motor is running, controlled rectifier 102 will be switched to its low impedance state by the current pulse from photocell 54 overcoming the gate voltage supplied through transformer T-1 and will essentially represent a short circuit. This will again establish a current flow through the timer 114 to start it running again. After another interval of timer, preferably about 5-10 seconds, switch S-1 will be switched back to its original position so that contactor 112 engages pole 110. This removes the supply voltage from controlled rectifier 102 and resets it in its high impedance state, also supplying direct line power to timer 114. After yet another period of time preferably about 5-10 seconds, the timer will actuate switch S-2 through connection 133 back to its original position so that contactor 132 is now in engagement with pole 130. This breaks the current flow through solenoid 134 so that contactors 135, 136 and 137 are opened to stop the motor. The timer will continue to run for a predetermined period of time in order to let the fluid refill the well casing from the productive earth formation and to eliminate or substantially decrease "fluid pound," preferably being about 14 minutes. After this period of time, the timer has returned to its original position and again closes switch S-2 to re-actuate the motor, and the same cycle as just described proceeds.

The time delay that is provided between the time that switch S-2 is actuated to its down position and the time that switch S-1 is actuated to its down position is to insure that controlled rectifier 102 is not connected into the line voltage during the time that the motor is being turned on. This is to prevent an excessive current peak, which occurs initially in turning on the motor, from being applied across the controlled rectifier as a voltage spike which could cause damage. The time delay that is provided between the time that switch S-1 is returned to its initial, or "up," position and the time that switch S-2 is returned to its initial, or "up," position is to also insure that the controlled rectifier is protected from transient voltages when the motor is being turned off.

A choke 108 is connected between the negative side of diodes 105 and 107 and the anode of controlled rectifier 102 for the purpose of sustaining the holding current through the rectifier during its initial turn on, so that the rectifier 102 is insured of being turned on when the proper gating signal is applied thereto. In other words, the controlled rectifier can be turned on only in response to a current pulse from detector 54 applied to the gate of the controlled rectifier simultaneously with a supply voltage applied across the controlled rectifier. Since the sup-

ply voltage applied to the rectifier from the bridge through transformer T-2 is in the form of a pulsating D.C. voltage, the controlled rectifier would be turned off as this supply voltage drops to zero each half cycle of the supply voltage. However, choke 108 acts to sustain the current passing through the rectifier when it is initially turned on to prevent this current from dropping below the holding current.

Mention has been made of the function of capacitor 94 as filtering the pulsating D.C. voltage from the rectifier bridge derived through transformer T-1, so that the negative voltage applied to the gate of the controlled rectifier essentially follows the curve of FIGURE 2. This capacitor, in addition, serves another very important function, which is the "spreading out" or averaging of the current drawn by the motor during "fluid pound" as shown by curves A, B and C over an extended angular position of the crank angle, so that the pulse from detector 54 will have a wider range of crank angle position to coincide with this decreased current. This obviates the necessity of critical positioning of the crank angle detector. This is especially beneficial in that the lamp 48 is supplied by a 60 cycle alternating voltage, which could be at a reduced intensity at the time the reduced current is detected if the averaging effect of capacitor 94 was not utilized. The margin of error is further increased by virtue of the fact that detector 54 responds to the lamp over a range of angular positions of the rocking beam as noted above.

Another desirable feature results from the circuit just described as a consequence of the various time intervals between the opening and closing of switches S-1 and S-2. When the motor is first actuated by closing switch S-2 prior to the closing of switch S-1, the motor is allowed to fully start and draw steady state current before controlled rectifier 102 can be switched to its low impedance state. This precludes the stopping of the motor of the pump as a result of any false indication of current of insufficient magnitude being drawn by the motor during the priming of the pump.

A part of the timer including switches S-1 and S-2 is shown in FIGURES 6-A, 6-B, and 6-C. Both switches S-1 and S-2 are microswitches which, when engaged, will switch from one pole to the other and which will switch back to the original pole when disengaged. FIGURE 6-A shows the condition when switch S-2 is actuated to engage contactor 132 with pole 131 through connection 133 to actuate the motor. The timer consists of a conventional synchronous motor (not shown) which drives a pair of cams 113 and 133 fixed to a rotating shaft 160. It will be noted that mechanical connections 113 and 133 in FIGURE 5 corresponds to the cams having the same numeral designations. Cam 133 is substantially wider at its end which engages microswitch S-2 than is cam 113 at its end 113' which engages switch S-1. Moreover, the two cams are displaced angularly from each other as attached to shaft 160, so that the end 113' of cam 113 is disposed intermediate the lateral edges of cam 133.

As shaft 160 is caused to rotate in a counterclockwise direction by the synchronous timer motor, cam 133 will engage the actuating member 162 of a switch S-2 to close the circuit to solenoid 134 to actuate the pump motor. The timer will continue to run and rotate the two cams until the end 113' of cam 113 engages actuating arm 164 of switch S-1, as shown in FIGURE 6-B. Thus in FIGURE 6-A, only switch S-2 has been actuated, whereas in FIGURE 6-B, both switches S-1 and S-2 have been actuated. It is at this point that the timer will be caused to stop if the current drawn by the pump motor is sufficient to indicate the absence of "fluid pound." It will be recalled that this is the condition where controlled rectifier 102 remains in its high impedance state, so that no current is passed through the timer so that the timer motor stops. Upon detecting a current which indicates

"fluid pound," the controlled rectifier is switched to its low impedance state to restart the timer. Cams 113 and 133 continue to rotate in a counterclockwise direction of shaft 160 so that cam 113 disengages actuating arm 164 of switch S-1, as shown in FIGURE 6-C. The timer will still continue to run and finally cam 133 will disengage actuating arm 162 of switch S-2 after the above-noted time interval following the disengagement of cam 113 and switch S-1. It will then take a period of approximately 14 minutes for the timer shaft 160 to make a complete rotation so that it returns to its original position shown in FIGURE 6-A.

Variable resistor 142 is provided in the controlled rectifier gate signal circuit from photocell 54 to adjust the magnitude of the current gate signal in relation to the current drawn by the pump motor measured through transformer T-1. This allows the discretionary judgment of what level of motor current that the motor is turned off when "fluid pound" occurs. Variable resistor 100 is for fine adjustment of all circuit components in relation to each other.

In many cases it is desirable to achieve production in the case where the fluid condition within the well is represented by a small production capability but with only a small amount of "fluid pound," such as denoted by curve C of FIGURE 2, for example. That is to say, a compromise is made to pump fluid under these conditions with admittedly less production capability but also with less "fluid pound" and wear on the machinery. By varying resistor 142 accordingly, the magnitude of the pulse from the photocell 54 can be reduced to below that required to switch the controlled rectifier for much smaller motor currents. Because of the averaging function of capacitor 94, which essentially widens the range of comparison of the crank angle and the motor current, this adjustment can be readily made with the variance of resistor 142 above. This would not be the case where the averaging function of capacitor is absent so that the range of comparison is very acute. In such a case, a physical readjustment of the means for measuring the crank angle would have to be made, which is very impractical.

Reset switch 116 is provided to stop the running of timer 114 when the system is installed on a well pump, so that the proper position of the pendulum system on the rocking beam and the setting of resistors 100 and 142 can be ascertained without having to wait for the timer to travel through the 14 minute interval on an erroneous indication. The reset switch is manually depressed when it is visually observed that the timer motor is running, while at the same time, a current motor is utilized to observe that the motor current is in excess of the "fluid pound" condition during installation.

Many modifications and substitutions that do not depart from the scope and intent of the invention will undoubtedly become apparent to those skilled in the art, such as, for example, different signal producing means which are gravity actuated to measure the crank angle, or other equivalent means for providing the various circuit functions. Therefore, it is intended that the invention be limited only as defined in the appended claims.

What is claimed is:

1. A system for controlling the operation of an electric motor of a well pump for driving a reciprocating member for pumping liquid from a well, comprising:

(a) first means for connection to said pump for producing a first signal over a substantial arc of the downstroke of said reciprocating member,

(b) second means connected to said first means, and for connection in circuit relationship with said electric motor for producing a second continuous signal which is a function of the current drawn by said motor during the downstroke of said reciprocating member, operative to compare the magnitude of said first signal with the magnitude of said second signal so as to disconnect said motor from its electrical

power source when the current drawn by said motor is less than a predetermined magnitude upon the occurrence of said first signal, and for reconnecting said motor to its electrical power source a predetermined time interval after said motor has been disconnected from its electrical power source.

2. A system for controlling the operation of an electric motor of a well pump for driving a reciprocating member for pumping liquid from a well, comprising:

(a) first means for connection to said pump for producing a first electrical signal having a substantially constant, predetermined magnitude over a substantial arc of the downstroke of said reciprocating member,

(b) second means for connection in circuit relationship with said motor for producing a second electrical signal whose magnitude is a function of the magnitude of the current drawn by said motor during the downstroke of said reciprocating member, and

(c) third means connected to said first and said second means for comparing said magnitude of said first signal upon the occurrence thereof with the magnitude of said second signal and responsive to disconnect said motor from its electrical power source when the magnitude of said second signal is less than said predetermined magnitude of said first signal, and for reconnecting said motor to its electrical power source a predetermined time interval after said motor has been disconnected.

3. A system according to claim 2 wherein said second electrical signal is a filtered, D.C. voltage.

4. A system according to claim 2 wherein said first means comprises a gravity actuated switch means for connection to said reciprocating member.

5. A system according to claim 2 wherein said first means comprises a pendulum for attachment to said reciprocating member actuated in response to the motion of said reciprocating member, and switch means operatively associated with said pendulum for producing said first signal over a substantial portion of the path of motion of said pendulum that corresponds to said substantial arc of the downstroke of said reciprocating member.

6. A system according to claim 5 wherein said switch means comprises a lamp and a photocell electrically connected to said third means, with one of said lamp and said photocell being fixed in relation to said reciprocating member and the other of said lamp and said photocell being fixed to said pendulum and optically coupled to said one of said lamp and said photocell when said pendulum passes through said substantial portion of the path of movement thereof.

7. A system according to claim 6 including shield means for optically shielding said photocell from said lamp as said pendulum passes through the upstroke of said reciprocating member.

8. A system according to claim 2 wherein said first means includes fourth means for varying said predetermined magnitude of said first signal.

9. A system for controlling the operation of an electric motor of a well pump for driving a reciprocating member for pumping liquid from a well, comprising:

(a) first gravity actuated switch means for connection to said reciprocating member and responsive to the motion thereof for producing a first voltage signal

over a substantial arc of the downstroke of said reciprocating member,

(b) current sensing means for connection in circuit relationship with said motor to produce a second continuous, filtered D.C. voltage signal whose magnitude is a function of the magnitude of the current drawn by said motor,

(c) second switch means connected to said first switch means and said current sensing means actuated in response to said first voltage signal when the magnitude of said second voltage signal is less than the magnitude of said first voltage signal,

(d) third switch means for disconnecting said motor from its electrical power source when opened, and

(e) timer means connected to said second and said third switch means and actuated in response to the actuation of said second switch means to open said third switch and then close said third switch means a predetermined time interval after said third switch means has been opened.

10. A system according to claim 9 including fourth switch means connected between said timer means and said second switch means operated by said timer means to preclude said second switch means from actuating said timer means for another predetermined period of time means after said timer has closed said third switch means.

11. A system according to claim 10 wherein said second switch means comprises a semiconductor controlled rectifier, and said first and said second voltage signals are applied to the gate electrode thereof.

12. A system according to claim 9 wherein said current sensing means includes a capacitor that is charged and discharged to produce said second filtered D.C. voltage signal, and said first switch means is interconnected to said current sensing means and said first voltage signal is filtered by said capacitor.

13. A system as set forth in claim 10 wherein said timer means includes a timer motor, said third switch means comprises a first switch that includes a first arm for closing said first switch when engaged and a first cam connected to said timer motor for rotation therewith that engages said first arm at a first angular position of said timer motor and disengages said first arm at a second angular position of said timer motor, and said fourth switch means comprises a second switch that includes a second arm for closing said second switch when engaged and a second cam connected to said timer motor for rotation therewith that engages said second arm at a third angular position of said timer motor between said first and said second angular positions when said first arm is engaged by said first cam and disengages said second arm at a fourth angular position of said timer motor between said first and said second angular positions when said first arm is still engaged by said first cam.

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