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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : E21B 47/10	A1	(11) International Publication Number: WO 97/46793
		(43) International Publication Date: 11 December 1997 (11.12.97)

(21) International Application Number: PCT/US97/09632

(22) International Filing Date: 2 June 1997 (02.06.97)

(30) Priority Data:
60/019,088 3 June 1996 (03.06.96) US

(71) Applicant *(for all designated States except US)*: PROTECHNICS INTERNATIONAL, INC. [US/US]; Suite 444, 1160 Dairy Ashford, Houston, TX 77079 (US).

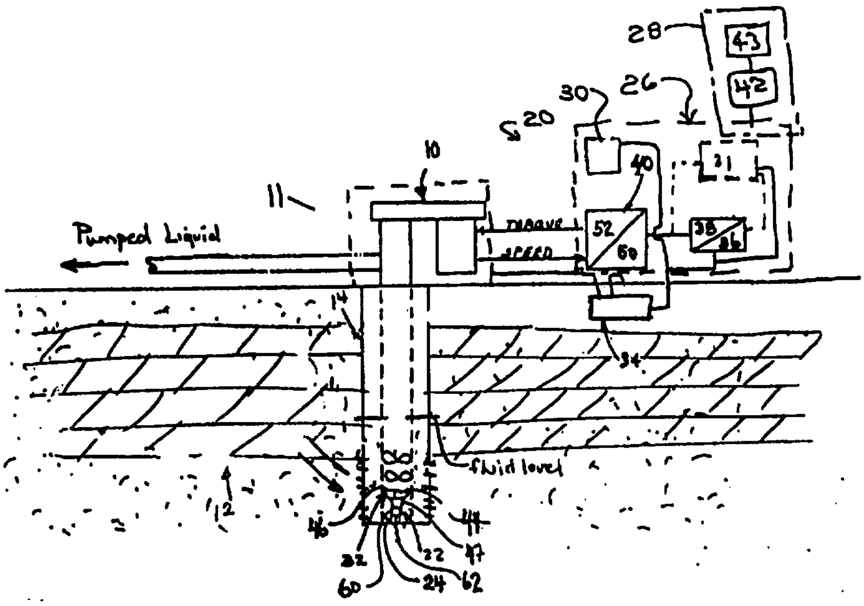
(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: BANDY, Thomas, R. [US/US]; 1603 Laguna Meadows Lane, Houston, TX 77094 (US). HAMPTON, John, T., III [US/US]; 8215 Silent Cedars, Houston, TX 77095 (US). TRAINOR, William, F. [US/US]; 15519 Rio Plaza, Houston, TX 77083 (US). FOREMAN, James, R. [US/US]; 1507 Brair Cottage Court, Sugar Land, TX 77479 (US). WANG, Zhenyu [CN/US]; 1803 Knollwood Drive, Middletown, NJ 07748 (US).

(74) Agents: FACTOR, Jody, L. et al.; Law Offices of Dick and Harris, Suite 3800, 181 W. Madison Street, Chicago, IL 60602 (US).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: WELLHEAD PUMP CONTROL SYSTEM



(57) Abstract

A wellhead pump control system (20) for artificial lift systems controls a motor of a wellhead pump that is removing fluid from within a well. The system (20) includes a downhole well tool (22) having sensing devices (32) which measure particular conditions of the well and of the fluid being removed. A transmitter (60) transmits the sensed condition to a surface data analysis apparatus (26). The surface data analysis apparatus (26) then compares the downhole measurements with desired predetermined measurement parameters, and calculates optimum wellhead pump motor operation from the compared measurements to determine whether the pump is properly adjusted for optimal performance, relative to fluid removal. If it is not, the calculated information can be used to manually, or automatically adjust the pump motor (e.g. speed and torque) for optimal performance.

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TITLE OF THE INVENTION

WELLHEAD PUMP CONTROL SYSTEM

This application depends from, and claims priority of, U.S. Provisional Application Ser. No. 60/019,088.

1. **FIELD OF THE INVENTION**

The present invention is directed to artificial lift systems, and, more particularly, to wellhead pump control systems for use with artificial lift systems.

2. **BACKGROUND OF THE INVENTION**

Artificial lift systems have been known in the art for many years. Specifically, such devices are typically used in oil and gas fields and the like, for removing fluid from an underground gas or oil producing reservoir. An example of a conventional artificial lift arrangement is shown in Fig. 1, as including well casing 110 (having perforations 125) installed inside wellbore 112, pump 115, receiver 117 (such as a pipeline or storage tank), pump motor 120, and motor speed controller 122.

In operation, fluid (such as oil, water, etc.), existing in an underground reservoir 124, enters well casing 110 through perforations 125 in the well casing. As the fluid enters the well casing, the pump 115 withdraws the fluid and delivers it to a surface collection point 117, such as a pipeline or tank.

In an attempt to pump fluid out of well casing 110 at a rate commensurate with its inflow from the underground producing reservoir 124, a well operator alters the pump speed through manual or automated adjustments at a surface motor speed controller 122. Failure to make such adjustments, or to make proper adjustments, could result in several problems. For example, if the pump speed is too high, there is the danger of withdrawing fluid too quickly, to, in turn, run the down hole pump dry, which results in damage to the pump. If the pump speed is too low, fluid could accumulate in the casing and create a backpressure on the fluid reservoir -- thereby hindering the rate at which the fluid would otherwise flow into the well casing. In either case, not only is there a risk of equipment breakdown, but, fluid removal does not occur at an optimum efficiency. Furthermore, efforts to operate at an optimum pump speed are often compromised in favor of protecting the downhole pump and piping, often resulting in less than optimum well performance.

SUMMARY OF THE INVENTION

The invention comprises a surface wellhead pump control system which controls the motor speed of a wellhead pump that is removing fluid from within a well. The system comprises a downhole well tool having means for sensing downhole measurements, as well as means for transmitting the downhole measurements to a surface data analysis apparatus. For example, the downhole measurements may comprise downhole pressure and temperature proximate the downhole well tool. Accordingly, the downhole well tool contains temperature and pressure sensors and other sensors as well, such as torque and other measurement sensors.

The surface data analysis apparatus includes means for receiving the downhole measurements from the transmitting means, and means for comparing the received downhole measurements with desired predetermined measurement parameters. These desired parameters are typically associated with the well and the fluid being removed from a particular well. Additionally, the surface data analysis apparatus includes means for calculating optimum wellhead pump motor speed operation from the received downhole measurements, and, in turn, means for adjusting the operating parameters of the wellhead pump motor to the calculated optimum values -- so as to optimize the rate at which fluid is removed from the well.

In a preferred embodiment of the invention, the surface data analysis apparatus may further include means for learning the unique characteristics of a particular well.

In another preferred embodiment, the system may include means for alerting an operator when any of the downhole measurements depart from an acceptable range of measurement parameters. In such an embodiment, the alert means may include means for activating a remote receiver or pager to notify the appropriate maintenance operator.

The invention may further include means for updating the downhole measurements at predetermined desired intervals of time. Such updating insures that optimum fluid removal rates are maintained regardless of changes in well producing behavior. For example, the adjustment means may be configured to alter the speed and the torque of the wellhead pump motor. Such alteration will be made to enable the pump to operate at or near optimal performance relative to fluid removal for the particular well, as well as safe and prudent operation of the equipment.

The invention further includes a method for controlling a wellhead pump comprising the steps of: (a) sensing certain downhole measurements at a downhole well tool; (b) transmitting those measurements to a surface data analysis apparatus; (c) receiving the downhole measurements at the surface data analysis apparatus; (d) comparing the received measurements with desired predetermined measurement parameters associated with the particular well and fluid being operated; (e) calculating optimum wellhead pump motor operation from the received downhole measurements; and (f) adjusting the operating parameters of the wellhead pump motor to optimize the rate at which fluid is removed from the well, to, in turn, insure the safe and prudent operation of that pump.

In a preferred embodiment, the method may further include the step of alerting an operator when the downhole measurements depart from a desired range of acceptable values.

In another preferred embodiment, the method may further include the step of updating the downhole measurements at predetermined intervals of time.

In yet another preferred embodiment, the method may further include the steps of: (a) learning the operating characteristics of the well; and (b) storing the learned operating characteristics of the well. In such a preferred embodiment, the step of learning may comprise the steps of: (a) setting the operating parameter of the wellhead pump motor to a predetermined set of operating parameters; (b) sensing certain measurements from the downhole well tool; (c) storing the downhole measurements; (d) repeating the foregoing steps as necessary for each of the desired range of operating parameters; and (e) computing the optimized operating characteristics of the well.

In such a preferred embodiment, the invention may further include the step of remeasuring and reanalyzing the operating characteristics of the well at predetermined time intervals.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic illustration of a conventional, prior art, artificial lift system;

Fig. 2 is a schematic illustration of a lift system having the wellhead pump control system of the present invention; and

Fig. 3 is a schematic illustration of the downhole tool contemplated for use with the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

While this invention is susceptible of embodiment in many different forms, there is shown in the drawings and will herein be described in detail, two specific embodiments, with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the invention to the embodiments illustrated.

Wellhead pump control system 20 is shown in Fig. 2 as comprising downhole well tool 22, transmitting means 24, surface data analysis apparatus 26, operator alert means 28, and, updating means 30. As will be explained, the updating means is used to update particular measurement data. In a preferred embodiment of the invention, wellhead pump control system 20 may include a conventional bottom hole progressive cavity pump, the operating desired speed and torque of which is controlled by a conventional variable frequency pump. Such a pump may be obtained from Energy Ventures Incorporated or National Oilwell, both of Houston, Texas.

Downhole well tool 22 is shown in Fig. 2 (and in Fig. 3 as operatively positioned within a conventional bottom hole assembly) as including sensing means 32 which serves to measure the particular downhole data and power source 47. In this case, the sensing means includes temperature sensor 44 and pressure sensor 46. Temperature sensor 44 may comprise a conventional transducer capable of obtaining accurate temperature measurement in excess of 300°F (148.8°C), while pressure sensor 46 may comprise a conventional strain gauge or quartz crystal pressure transducer which is capable of obtaining accurate pressure readings in excess of 15,000 psi (pounds per square inch). Pressure sensor 46 indirectly determines the depth at which the fluid level is located above the downhole well tool 22 within the well in which downhole well tool 22 is positioned. While temperature and pressure sensors have been identified for use, it is likewise contemplated that multiple sensors, including sensors having other data measuring capabilities, can be used in association with downhole well tool 22 -- provided such sensors are operational within the particular downhole environment in which the downhole well tool will be installed.

Power source 47 of downhole well tool 22 may be attached directly to downhole well tool 22, and, may comprise batteries such as conventional "AA", "B", or "C" cell alkaline or lithium batteries, as well as customized, long-lasting batteries suited for extended use. Of course, other applicable conventional power sources, as would be readily understood to those with ordinary skill in the art, are likewise contemplated. For example, downhole well tool 22 may be powered from a surface generator coupled through electric cabling from the surface.

Transmitting means 24 is shown in Fig. 2 as comprising transmitter 60. The transmitting means serves to transmit the measured downhole data measurements, from the sensing means, to surface data analysis apparatus 26. The transmitter may be positioned on the downhole tool, or, proximate thereto, as a stand-alone unit. Additionally, transmitter 60 may share power source 47 of sensing means 32, or, alternatively, transmitter 60 may be powered by a separate power source.

In one embodiment, transmitter 60 may comprise a conventional transmitter capable of transmitting the measured downhole measurements from downhole to surface data analysis apparatus 26. One example of such a conventional transmitter includes, but is not limited to, a subsurface modulated electromagnetic frequency (EMF) antenna. Such an antenna may likewise comprise toroids, gap-subs and/or hardwired data transmission technology. As will be explained in further detail, in such an embodiment, the transmitter transmits the measurement, representative of, for example, the bottom hole fluid pressure and temperature data to receiver 34 (associated with surface data analysis apparatus 26).

Surface data analysis apparatus 26 (which may comprise a computing device) is shown in Fig. 2 as including receiving means 34, comparing means 36, calculating means 38, and adjustment means 40. Receiving means 34 may comprise a conventional receiving device which is suitable for receiving and processing the downhole measurements received from transmitting means 24. For example, and in operation, receiving means 34 may be connected to wellhead 11 (Fig. 2) and the ground for sensing the voltage potential at the wellhead (which represents the signal from transmitter 60 in downhole well tool 22). In an embodiment where the transmitting apparatus comprises an EMF transmitter, the receiver may comprise an EMF antenna coupled with a conventional surface receiver.

Additionally, receiving means 34 may be provided with appropriate circuitry and programming to filter and/or amplify the received measurement/signal, to, in turn, clarify the signal by reducing/eliminating other interfering electrical noise from the signal. Inasmuch as the signal often travels extended distances through the ground and is susceptible to other electrical interference, the received measurements often require clarifying, filtering and/or amplifying.

Data comparing means 36, calculating means 38 and motor operating adjustment means 40 are all part of surface data analysis apparatus 26, and are each programmed using conventionally known programming techniques to perform various functions. Specifically, after receiving means 34 receives the transmitted measurements/signals, data comparing means 36 compares the received downhole measurements with desired (and programmed) measurement parameters associated with the particular well and fluid being removed from the well. Calculating means 38 then calculates the optimum wellhead pump motor operation parameters (for the particular well), based on the compared received data. If the calculations reveal that the pump motor is not operating optimally (i.e. speed and torque) for the particular well, then adjustment means 40, as will be explained, alters the speed and/or torque to such optimal settings.

Adjustment means 40, as shown in Fig. 2, comprises signal generator 50 and pump motor speed controller 52. The signal generator is capable of transmitting desired output parameters to the motor controller which, in turn, implements these altered output parameters to the wellhead pump motor. For example, the motor controller may comprise a commercially available device such as Toshia. In addition to speed and torque, surface data analysis apparatus 26 may also be capable of comparing, calculating and adjusting other data inputs, such as "maximum and/or minimum flow line pressure", "maximum and/or minimum sucker rod torque", "maximum and/or minimum drive speeds", "pump rpm", "pump current", etc.

Surface data analysis apparatus 26, in combination with transmitting means 24, may further include measurement updating means 30. Such updating means 30 transmits downhole measurements, at predetermined time periods, (from sensing means 32) to surface data analysis apparatus 26. At each time period, the downhole measurements will be subjected to comparing means 36 and calculating means 38. Accordingly, in one embodiment, if the motor pump parameters at that specific time period differ from optimum motor pump parameters, such differences will then result in adjustment means 40 causing, for example, real time adjustments to the pump motor. Alternatively, if adjustments are required, the adjustment means may alert a maintenance operator (as will be more fully explained) who will then make the appropriate adjustments to the pump motor in accordance with the calculated optimum pump parameters. Updating means, and in particular, triggering the receiving and transmitting of downhole measurements (at predetermined time intervals) can be accomplished through conventional programming techniques as would be readily understood to those with ordinary skill in the art.

The invention additionally contemplates operator alert means 28 for alerting a maintenance operator (at, for example, a remote location) of any adverse condition associated with the well pump motor (including non-optimal performance). The alert means may be programmed into surface data analysis apparatus 26 and may include receiver actuator 42 and receiver 43. Remote receiver actuator 42 may comprise a conventional transmitter for triggering receiver 43. Upon detection of an adverse pumping condition, which could be relative to fluid removal from the well (as determined by comparing means 36) receiver actuator 42 transmits an alerting indication to receiver 43, which alerts the maintenance operator of the potential problem. For instance, the receiver actuator may comprise a telephone/modem, and receiver 43 may comprise a remote terminal or other device such as a cellular telephone or pager which the maintenance operator may have on his person. Likewise, other conventional transmitter/receiver devices, such as two-way radios, personal computers, PDA's, and the like are also contemplated. The alerting indication may comprise an audio signal, video signal or any combination of audio and visual signals which are receivable, through receiver 43, by a maintenance operator.

In operation, downhole well tool 22 of automated wellhead pump control system 20 is positioned and is lowered down a well through conventional techniques. As will be understood, the well itself is bored out proximate to an underground reservoir, for removal of fluid therefrom. Sensing means 32 of tool 22, when activated, receives downhole measurements (data) as to the pressure and temperature at the downhole tool location in the well. As explained above, specialized sensors may likewise be positioned to take readings other than temperature and pressure.

Preferably, 1 - 3 pressure and temperature measurements are made over a span of 24 hours. Between measurements, the sensing means is temporarily turned off. However, it is also contemplated that sensing means 32 may remain activated constantly. However, the selective activation/deactivation, as needed, conserves power and extends sensor life. This increases the length of time the downhole tool can stay in the well, which is highly desirable, inasmuch as the replacement of the downhole tool and its power supply typically requires downtime and, in turn, adversely affects operating costs and production output.

The wellhead measurements obtained are transmitted by transmitting means 24 via receiving means 34 to surface data analysis device 26. While other locations are contemplated, the surface data analysis device 26 may be situated in the field office thereby reducing the need for well operators to visit individual well sites. Thus, instead of having to personally inspect each well on a daily basis, visits to a well can be limited to only those necessary to address potential trouble situations or to perform preventive maintenance.

Once the signals are received from transmitting means 24, and amplified and filtered, comparing means 36 compares the received downhole measurement to known or desired parameters preprogrammed and stored within the surface data analysis apparatus 26. The tabulation of these known or desired parameters may be based on mathematical analysis, or based on prior gathered information regarding the particular well or other wells with similar properties.

Once the downhole measurements are compared to the desired parameters, the calculating means 38 calculates the optimum parameters for the wellhead pump motor. After the calculations have been made, the adjustment apparatus 40 adjusts the output parameters of the wellhead pump, if needed, to operate based on the calculated optimal values. These optimal values translate into the maximum safe fluid removal rates. While other parameters are contemplated for specific purposes, the adjustment apparatus is capable of altering, or causing to be altered, the speed and the torque outputs of the wellhead pump motor.

In another embodiment, the automated wellhead pump control system 20 is provided with a learning mode wherein the surface data analysis apparatus can "learn" the optimum wellhead pump motor parameters through trial and error, as well as through conventional mathematical modeling methods. In such an embodiment, surface data analysis apparatus 26 further includes means 31 for learning the characteristics of the particular well. The learning means uses adjustment means 40 to set several wellhead pump motor output parameters. At each of the set output parameters, learning means 31 stores the downhole measurements received by the receiving means 34. Subsequently, through various algorithms, such as interpolation, trial and error, or other conventional computations, learning means 31 is capable of generating a mathematical model embodying the characteristics of the well, toward determining the resulting optimal pump operating parameters. More specifically, the mathematical model used toward determining the maximum removal rate of the fluid from the particular well can be obtained without risk of damage to any of the equipment (such as the pump).

In operation of this embodiment, automated wellhead pump control system 20 first executes a learning mode. The learning mode essentially begins with a desired set of well pump motor output parameters. Sensing means 32 senses the downhole measurements and transmitting means 24 transmits these to learning means 31 of surface data analysis apparatus 26. Learning means 31 may be configured to use several sets of determined pump motor output parameters for which the foregoing procedure is repeated. Once the values for the downhole measurements have been received and stored, the learning means 31 computes a mathematical model of the particular operating characteristics of the well. Learning means 31 maintains this computed mathematical model as the operating characteristics of the well. The mathematical model, maintained by the learning means, is used by comparing means 36 and calculating means 38 to determine optimum wellhead pump motor parameters toward maximizing safe fluid removal rates.

In this embodiment, update means 30 is configured to trigger the operation of the learning means 31 to recompute the operating characteristics of the well at predetermined intervals of time. For each interval, the learning means obtains new downhole measurements to compute an updated mathematical model of the operating characteristics of the well.

The present invention is believed to provide several advantages. The invention permits the maximum fluid to be removed from the well, without damaging the equipment. This results not only in greater fluid removal rates, but also in reduced down-time and lower maintenance costs. Further, inasmuch as downhole measurements may be gathered on a real-time basis, potentially dangerous well conditions may be uncovered and responded to quickly. Moreover, no moving parts or downline wires are required, reducing outside interference with the well during operation.

The foregoing description and drawings merely explain and illustrate the invention and the invention is not limited thereto except insofar as the appended claims are so limited, as those skilled in the art who have the disclosure before them will be able to make modifications and variations therein without departing from the scope of the invention.

CLAIMS

1. A wellhead pump control system for controlling the operation of a motor of a wellhead pump which is removing fluid from within a well, the system comprising:

- a downhole well tool having sensing means for measuring at least one downhole measurement;

- transmitting means for transmitting the downhole measurement to a surface data analysis apparatus; and

- a surface data analysis apparatus including,

- receiving means for receiving the at least one downhole measurement transmitted by the transmitting means;

- means for comparing the received at least one downhole measurement with desired predetermined measurement parameters associated with the particular well and fluid being removed therefrom;

- means for calculating optimum wellhead pump motor operation from the compared received downhole measurements with the desired predetermined measurement parameters;

- means for adjusting the operating parameters of the wellhead pump motor to optimize of the rate at which fluid is removed from the well.

2. The system according to claim 1 wherein the sensing means comprises:

- at least one of a pressure sensor and a temperature sensor.

3. The system according to claim 1 wherein the adjustment means determines appropriate altering of at least one of the speed and the torque of the wellhead pump motor, so as to enable optimum well pump performance.

4. The system according to claim 1 further comprising:

- operator alert means for alerting an operator when the at least one downhole measurement departs from a predetermined range of measurement parameters, the operator alert apparatus being associated with the surface data analysis apparatus.

5. The system according to claim 4 wherein the operator alert apparatus includes means for activating a remote receiver.

6. The system according to claim 1 further comprising:

- means for updating the at least one downhole measurement at a predetermined desired interval of time to insure that the desired wellhead pump speeds and optimum fluid removal rates are maintained.

7. A method for controlling a wellhead pump associated with a well, the method comprising the steps of:

- sensing at least one downhole measurement at a downhole well tool;

- transmitting the at least one downhole measurement to a surface data analysis apparatus;

- receiving the at least one downhole measurement by the surface data analysis apparatus;

- comparing the received at least one downhole measurement with desired predetermined measurement parameters associated with the particular well and fluid being removed therefrom;

- calculating optimum wellhead pump motor operation from the compared received downhole measurements with the desired predetermined measurement parameters; and

- adjusting the operating parameters of the wellhead pump motor toward optimization of the rate at which fluid is removed from the well.

8. The method according to claim 7 further including the step of:

- alerting an operator when the at least one downhole measurement departs from a predetermined range of values.

9. The method according to claim 7 further including the step of:

- updating the at least one downhole measurement at predetermined intervals of time.

10. A wellhead pump control system for controlling a motor of a wellhead pump that is removing fluid from within a well, the system comprising:

- a downhole well tool having means for measuring at least one downhole measurement;

- means for transmitting the at least one downhole measurement to a surface data analysis apparatus; and

- a surface data analysis apparatus including,

- means for receiving the at least one downhole measurement transmitted by the transmitting apparatus;

- means for learning the characteristics of the well;

- means for comparing the received at least one downhole measurement with learned characteristics of the well;

- means for calculating optimum wellhead pump motor operation from the compared received downhole measurements with the learned characteristics of the well;

- means for adjusting the operating parameters of the wellhead pump motor toward optimization of the rate at which fluid is removed from the well.

11. The system according to claim 10 wherein the learning means comprises, at least in part, software programming capable of processing received values to create a mathematical model of the well.

12. A method for controlling a wellhead pump associated with a well, the method comprising the steps of:

- learning the operating characteristics of the well;

- storing the learned operating characteristics of the well;

- sensing at least one downhole measurement at a downhole well tool;

- transmitting the at least one downhole measurement to a surface data analysis;

- receiving the at least one downhole measurement by the surface data analysis apparatus;

- comparing the received at least one downhole measurement with learned operating characteristics of the well;

- calculating optimum wellhead pump motor operation from the compared received downhole measurements with the learned operating characteristics of the well; and

- adjusting the operating parameters of the wellhead pump motor toward optimization of the rate at which fluid is removed from the well.

13. The method according to claim 12 wherein the step of learning further includes the steps of:

- setting the operating parameter of the wellhead pump motor to, at least one of a predetermined set of operating parameters;

- sensing at least one downhole measurement from the downhole well tool;

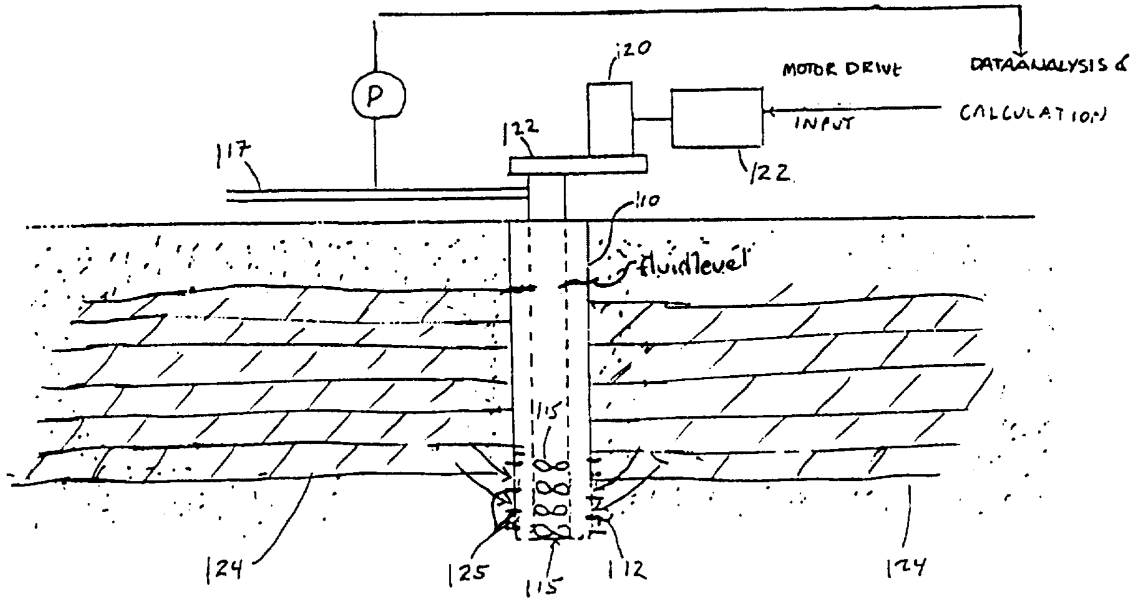
- storing the at least one downhole measurement;

- repeating the foregoing steps for each of the predetermined set of operating parameters; and

- computing the operating characteristics of the well.

14. The method according to claim 12 further comprising the step of:

- triggering the learning apparatus to recalculate the operating characteristics of the well.



PRIOR ART

FIG. 1

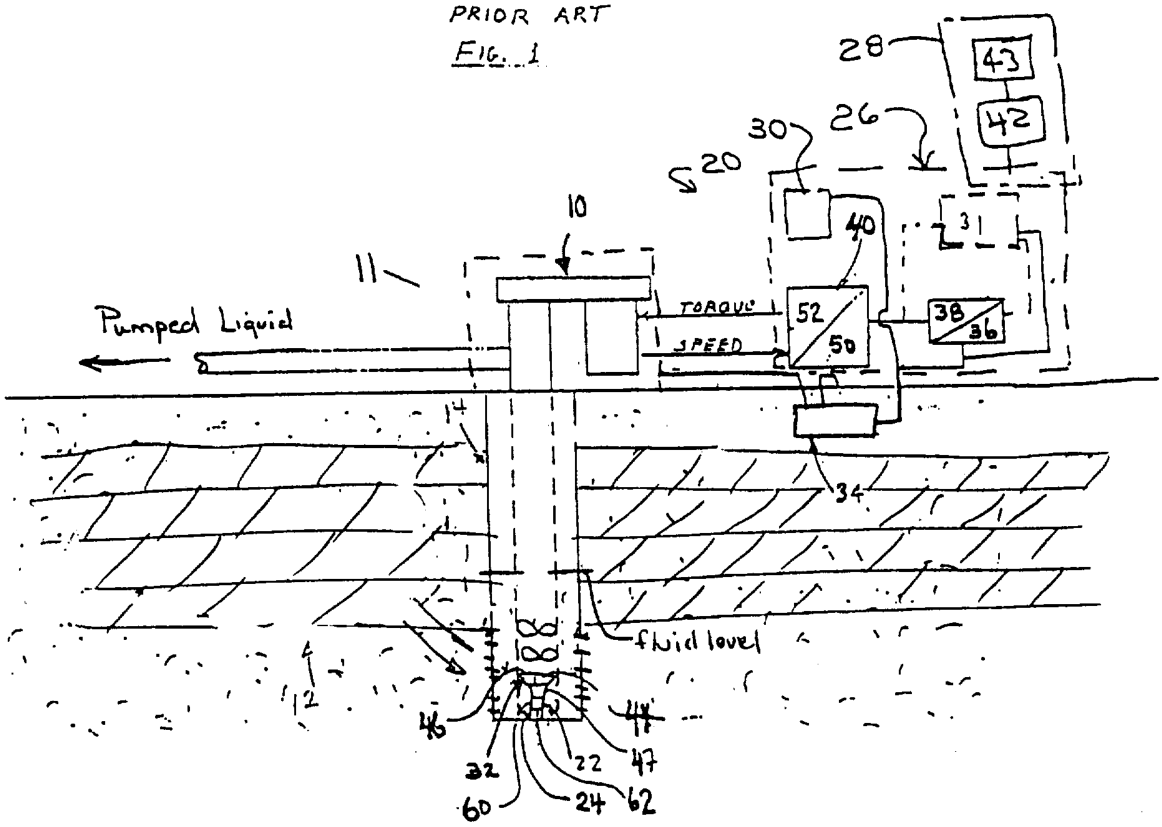


FIG. 2

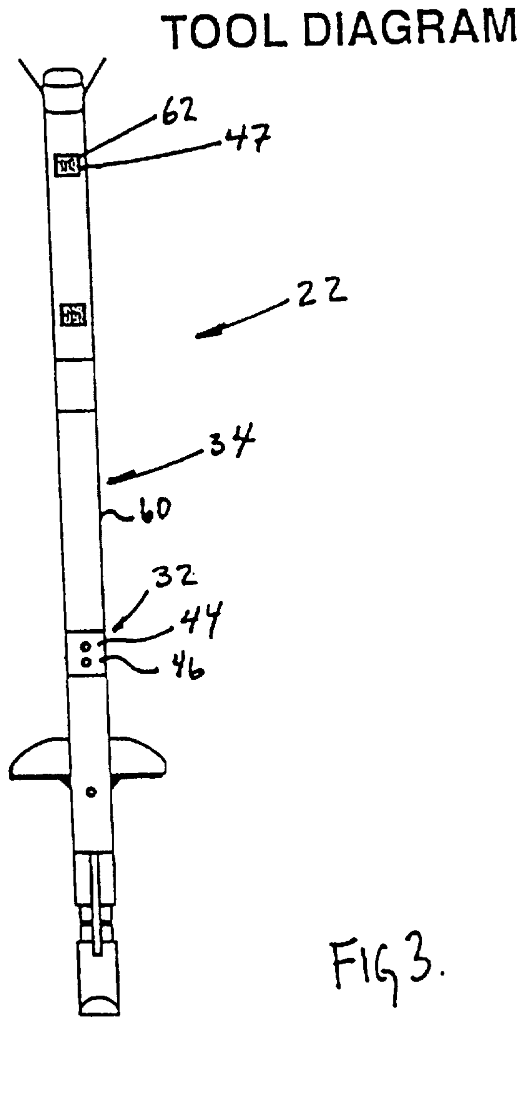


FIG 3.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/09632

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :E21B 47/10
US CL :166/250.15
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 166/250.15, 250.07, 370, 369, 53

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

none

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,461,172 A (MCKEE ET AL) 24 July 1984 (24/07/84), see entire document.	1-3 and 6-14
A	US 5,314,016 A (DUNHAM) 24 May 1994 (24/05/94), see entire document.	1-14

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Authorized officer
WILLIAM P. NEUDER
Telephone No. (703) 308-2168