FORM 1 SPRUSON & FERGUSON

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952 602995

APPLICATION FOR A STANDARD PATENT

Shell Internationale Research Maatschappij B.V., a Netherlands Company, of Carel van Bylandtlaan 30, 2596 HR, The Hague, THE NETHERLANDS, hereby apply for the grant of a standard patent for an invention entitled:

Method and Apparatus for Controlling a Pump ~~Measuring Differential Fluid Power Output of a Pump~~

which is described in the accompanying complete specification.

The address for service is:-

Spruson & Ferguson
Patent Attorneys
Level 33 St Martins Tower
31 Market Street
Sydney New South Wales Australia

DATED this EIGHTEENTH day of JULY 1988

Shell Internationale Research Maatschappij B.V.

By:

Registered Patent Attorney

PATENT OFFICE
18 JUL 1988
SYDNEY

TO: THE COMMISSIONER OF PATENTS
OUR REF: 65348
S&F CODE: 61750

PATENT OFFICE
001064
Collector of Public Moneys

APPLICATION ACCEPTED AND AMENDMENTS
ALLOWED 8 - 3 - 90

5845/2

~~T 8137 AUS~~

SPRUSON & FERGUSON

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952

DECLARATION IN SUPPORT OF AN APPLICATION FOR PATENT

In support of the application made by Shell Internationale Research Maatschappij B.V.
for a patent for an invention entitled:,
Method and Apparatus for Measuring Differential Fluid Power Output of a Pump

I Onno Aalbers

of Shell Internationale Research Maatschappij B.V.
Carel van Bylandtlaan 30, 2596 HR The Hague, the Netherlands

do solemnly and sincerely declare as follows:

1. I am authorised by Shell Internationale Research Maatschappij B.V., the applicant for the patent to make this declaration on its behalf.

2. DALE RICHARD SNYDER JR. and JOE HENRY HAWS, of 4802 Hickory Downs, Houston, Texas 77084, United States of America and 2307 Primrose Court, Richmond, Texas 77469, United States of America, are the actual inventor(s) of the invention and the facts upon which the applicant is entitled to make the application are as follows:-

The said applicant is the assignee of the actual inventors.

DECLARED at The Hague this 29th day of August 1986

....
Signature of Declarant(s)
Onno AALBERS

TO: THE COMMISSIONER OF PATENTS

SBR/as/151F

(12) PATENT ABRIDGMENT (11) Document No. AU-B-19175/88
(19) AUSTRALIAN PATENT OFFICE (10) Acceptance No. 602995

(54) Title
METHOD AND APPARATUS FOR CONTROLLING A PUMP SUBJECT TO VAPOUR LOCKS

International Patent Classification(s)
(51)[4] F04B 049/06 F04B 049/10 F04D 015/02

(21) Application No. : 19175/88 (22) Application Date : 18.07.88

(43) Publication Date : 31.05.90

(44) Publication Date of Accepted Application : 01.11.90

(71) Applicant(s)
SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V.

(72) Inventor(s)
DALE RICHARD SNYDER JR.; JOE HENRY HAWS

(74) Attorney or Agent
SPRUSON & FERGUSON, GPO Box 3898, SYDNEY NSW 2001

(56) Prior Art Documents
AU 574375 31594/84 F04B 49/00
AU 53005/86 F04B 49/00, F04D 15/02
EP 314249

(57) Claim

1. A method for controlling a pump comprising the steps of:
   (a) determining pump power consumption at timed intervals;
   (b) obtaining a recent pump motor power consumption from the determinations;
   (c) obtaining a previous pump motor power consumption from the determinations;
   (d) deriving the difference between the recent pump motor power consumption and the previous pump motor power consumption;
   (e) denoting the difference as differential pump fluid power output; and
   (f) shutting the pump down when the differential pump fluid power output exceeds a predetermined amount for a predetermined length of time.

13. An apparatus for controlling a pump comprising means for determining pump power consumption at timed intervals, means for obtaining a recent pump motor power consumption from the determinations, means for obtaining a previous pump motor power consumption from the determinations, means for deriving the difference between the recent pump motor power consumption and the previous pump motor power consumption, means for

.../2

denoting the difference as indicative of differential pump fluid power output when the difference exceeds a predetermined quantity, and means for shutting the pump motor down when the difference exceeds a predetermined quantity.

S & F Ref: 65348

FORM 10

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952

COMPLETE SPECIFICATION

(ORIGINAL) 602095

FOR OFFICE USE:

Class   Int Class

Complete Specification Lodged:
Accepted:
Published:

Priority:

Related Art:

Name and Address of Applicant: Shell Internationale Research Maatschappij B.V.
Carel van Bylandtlaan 30
2596 HR
The Hague
THE NETHERLANDS

Address for Service: Spruson & Ferguson, Patent Attorneys
Level 33 St Martins Tower, 31 Market Street
Sydney, New South Wales, 2000, Australia

Complete Specification for the invention entitled:

Method and Apparatus for Controlling a Pump ~~Measuring Differential Fluid~~ Power ~~Output of a Pump~~

The following statement is a full description of this invention, including the best method of performing it known to me/us

5845/3

ABSTRACT

METHOD AND APPARATUS FOR CONTROLLING A PUMP

Differential motor load drops or differential pump fluid outputs are employed to indicate gas lock or pump off of an electrical submersible or other pump.

KWK:855y

METHOD AND APPARATUS FOR CONTROLLING A PUMP

The use of soft starters for electrical submersible pumps (ESP's) within the past few years had led to an opportunity to increase production by pumping ESP's off, i.e., pumping well fluid levels down to the pump intake in order to obtain maximum production from a well by lowering its bottomhole pressure. Operating an ESP in this mode means that the ESP is continually cycled on and off as the unit is pumped off, shut down for a short period of time to allow the well to partially fill, and then restarted. This could not have been done prior to the use of soft starters since ESP failure was common on restart.

Besides minimizing restarting failures, a pump off operation also requires reliable pump off detection and control to not allow an ESP to operate after it has become gas-locked. Failure to shut down a gas locked ESP will result in premature failure due to overheating. Gas locking occurs when an ESP ingests sufficient gas so as to no longer be able to pump fluid to the surface, the result of either large gas bubbles being present in the well fluid or of the pump intake being uncovered at pump off. In accordance with the present invention an ESP pump off controller has been developed to meet the needs of reliably detecting and shutting down an ESP when gas locked or pumped off since existing ESP motor controllers have been proven to inadequately under these critical conditions.

Existing ESP motor controllers have been adapted from surface motor control packages where motor operation is more stable and motor control is less critical. For example, it is not critical for a motor controller to prevent a surface centrifugal pump from running dry since this will not damage the pump or its motor, but a downhole ESP will fail rapidly if it is run after losing fluid flow to the surface. These motor controllers monitor the running current (or power consumption) of the motor and compare it to a manually adjustable, fixed setpoint. When the current drops below this underload setpoint for a prescribed length of time, the motor is shut down.

Experience has shown that this existing method of motor control is unreliable since pumping ESP's are seen to be prematurely shutting down in underload or not at all. The reason for this unreliability is that the manually entered setpoints are often guessed, or at best, based on varying rules of thumb which may have no correlation to what is going on downhole.

As a result, setpoints are frequently set too high causing premature shutdown and loss of production or set too low failing to shut the ESP down, causing failure of the ESP and loss of production.

The primary purpose of the present invention is to provide a method and apparatus for shutting down a pump motor when a motor underload has occurred, for example due to pump off or gas lock. Gas locking and pump off have been found, as discovered in accordance with the present invention, to be characterized by a sudden drop in motor load and fluid power output when gas enters the pump.

According to a first embodiment of the present invention there is provided a method for controlling a pump comprising the steps of:

(a) determining pump power consumption at timed intervals;

(b) obtaining a recent pump motor power consumption from the determinations;

(c) obtaining a previous pump motor power consumption from the determinations;

(d) deriving the difference between the recent pump motor power consumption and the previous pump motor power consumption;

(e) denoting the difference as differential pump fluid power output; and

(f) shutting the pump down when the differential pump fluid power output exceeds a predetermined amount for a predetermined length of time.

According to a second embodiment of the present invention there is provided a method for controlling a pump driven by an electric motor comprising the steps of:

(a) determining motor loads at times intervals;

(b) obtaining a recent motor load from the determinations;

(c) obtaining a previous motor load from the determinations;

(d) deriving the difference between the recent motor load and the previous motor load;

(e) denoting the difference as indicative of pump motor underload when the difference exceeds a predetermined quantity; and

(f) shutting the pump motor down when motor underload is detected.

KWK:855y

According to a third embodiment of the present invention there is provided an apparatus for controlling a pump comprising means for determining pump power consumption at timed intervals, means for obtaining a recent pump motor power consumption from the determinations, means for obtaining a previous pump motor power consumption from the determinations, means for deriving the difference between the recent pump motor power consumption and the previous pump motor power consumption, means for denoting the difference as indicative of differential pump fluid power output when the difference exceeds a predetermined quantity, and means for shutting the pump motor down when the difference exceeds a predetermined quantity.

According to a fourth embodiment of the present invention there is provided an apparatus for controlling a pump driven by an electrical pump motor, the apparatus comprising means for determining motor loads at times intervals, means for obtaining a recent motor load from the determinations, means for obtaining a previous motor load from the determinations, means for deriving the difference between steps the recent motor load and the previous motorload, means for denoting the difference as indicative of pump motor underload when the difference exceeds a predetermined quantity, and means for shutting the pump motor down when motor underload is detected.

Several alternative methods and apparatus embodying the invention may be used to reliably determine if gas locking or pump off has occurred by measuring pump operating parameters at the surface. A preferred method uses the following logic: (1) computations are performed on measured motor load to determine if a drop in motor load has occurred. (2) For non-gassy pumping application, the ESP is shut down on the first indication of a drop in motor load. This will occur at pump off; gas will not enter the pump and cause motor load to drop until the fluid level in the well is pumped down and the pump intake is uncovered. (3) For gassy pumping application, the ESP is shut down only when it gas-locks. Motor load will drop each time gas enters

KWK:855y

the pump, but will recover when the gas exits with the pump fluid. When a large amount of gas enters the pump and the pump becomes gas-locked, motor load will drop but will not recover since the gas is trapped in the pump. In this application, the ESP is shut down if motor load drops and does not recover within an adequate length of time.

Preferably, the method (and apparatus for conduction the method) includes shutting the pump (or pump motor) down when the differential pump fluid power output exceeds a predetermined amount for a predetermined length of time (or when an underload is detected or alternatively, shutting the pump motor down when an underload is detected which exceeds a predetermined length of time).

Other purposes, distinctions over the art, advantages and features of the invention will be apparent to one skilled in the art upon review of the following description with reference to the accompanying drawing, in which: Figure 1 shows a flow diagram of a preferred controller sequence of steps developed in accordance with the present invention.

In accordance with the present invention several parameters are monitored independently, or in any combination to determine if a change in electrical submersible pump (ESP) motor load has occurred. These are apparent power, actual power, reactive power, power factor, and current (since voltage is generally constant). Each one of these parameters will drop when the ESP motor load drops. Ratios of combinations of these parameters may also be monitored since the ratios will change when motor load drops. If current is used to monitor motor load, voltage may also be measured as a secondary parameter to ensure current fluctuations are not the result of voltage spikes or sags, i.e., current can fluctuate due to other reasons than motor load. For example, the power company may not supply uniform voltages, or storms may cause variations, etc.

Motor load parameters can be measured with a variety of techniques. Parameters can be measured directly or can be first subjected to filtering or smoothing with a root mean square or averaging technique before being measured. Measurements can be taken in an analog fashion with mathematical calculations performed with analog circuitry. Alternatively, analog measurements can be converted to digital and mathematical computations performed with either digital hardware or with software such as in a microprocessor. Digital sampling rates, the length of time evaluated in computations, and data storage requirements are interrelated but can vary widely. In a preferred embodiment, the present invention used an analog-to-digital sampling rate of 4 Hz, although sampling rates less than once every 15 minutes may be used at different time period, or used in the computations as described hereinafter.

Unlike existing motor control technology that compares motor power or current to a setpoint, the control methods of the present invention utilize various techniques to determine if pump off has occurred as described hereinbelow. To determine if motor load has dropped, a comparison of the most recent motor load measurements may be made to any previous average motor load. Thus, the most recent motor load measurement can be a single data point or the average of many data points that last occurred. There is no limit to the number of data points or the length of time over which the average can be calculated. Testing of the present invention was successful when using the average of the most recent one second of current and also using just the last single point reading of current. The previous motor load average is preferably computed over any time interval from ESP start to the first data point used in the most recent average. One method of determining the previous motor load is to continually recalculate the moving average of the motor load for any set length of time prior to the most recent average data. There is no limit to the number of data points or the length of time over which the average is calculated. Testing of the present invention has successfully used a moving 5-second average of current. The required degree of drop in the motor load parameter must be established in order to identify a potential gas lock or pump off condition. This degree is dependent upon which parameter is being monitored, but is still quite flexible. In accordance with the present invention, a criteria that a current drop must be greater than 5 per cent was successfully shown but testing has also indicated that success may be obtained with a criteria anywhere from 1 per cent to 20 per cent and a wider range of one-quarter per cent to 30 per cent is possible although errors are more prone to occur in the wider range. In a gassy pumping condition, motor load must drop and remain down for a period of time before the ESP is shut down for gas locking. This required time the motor load must remain down is dependent on the length of time used in the averages in the above steps. In accordance with the present invention, there was successfully tested 10 seconds as one time criteria, but it was easily feasible to use anything greater than 2 seconds. However, this time limit could be cut to zero if longer time periods were used to calculate the two averages of motor loading. The maximum time limit is only a function of how much risk of damage it is possible to take with the ESP before shutting down (for example, an hour or more would be extreme).

Computation of the differential of motor load with respect to time is another way to determine if motor load has dropped.

Motor load is sampled at regular intervals as stated above and the differential motor load is calculated by subtracting the previous motor load from the most recent motor load, and dividing the difference by time between the two measurements. The previous and most recent motor load values can each be single point measurements or the averages of several measurements. A significant negative result indicates a drop in motor load such as when an ESP is gas locked or pumped off. The degree to which the differential must be negative depends on sampling rates and the time interval over which the differential is calculated. The ESP is pumped off if the differential becomes significantly negative and does not then become significantly positive. The differential method of controller calculation can be performed digitally or in an analog fashion.

Integration of the motor load for a given period of time is yet another way to calculate average motor loads.

Motor load is sampled at regular intervals as stated above and stored in a data array. The area under the motor load versus time curve is calculated for the most recent time period by using an integration technique. The most recent time period can be any length specified by the user depending on the sensitivity required (the shorter the length, the more sensitive the calculation to changes in motor load).

The integration controller calculated method can also be performed digitally or in an analog fashion. Gas locking or pump off is indicated if the most recent integration of motor load is less than the previous integration be a predetermined amount. The length of time over which the integrations are performed, whether the reference integration is calculated at a fixed point in time or on a moving basis, the degree of drop required to be significant, and the time required for the drop to remain down in gassy applications will all vary similarly as in the first method described above.

Finally, another way to determine if motor load has dropped is by performing a statistical analysis of motor load. As in the other methods, motor load is sampled at regular intervals and stored in a data array. The sample distribution statistics are calculated from the previous motor load samples taken for a given length of time and the most recent motor load sample is compared to it. Drops in motor load that fall outside of control limits calculated from the previous motor load sample distribution and the desired sample confidence interval indicate a significant drop in motor load has occurred. The confidence interval that is used is dependent on the probability of error that it is possible to accept and can vary accordingly. If the most recent sample of motor load falls below the calculated lower control limit for a predetermined length of time, then the ESP has gas locked or pumped off and is shut down. Additionally, a statistical calculation in motor load variance or standard deviation indicates that motor load has become more variable, another indication that gas has entered the pump or pump off has occurred.

The pump off/gas locking controlling developed in accordance with the present invention can be utilized in several ways. Thus, it is possible to be used as a controller subassembly. The developed controller is wired in series with an existing motor controller to augment/replace the underload functions of the existing controller. Alternatively, the apparatus can be integrated into a single motor controller package. Thus, it is necessary to replace the underload functions in a motor controller with the gas lock/pump off controller functions. Also alternatively, the apparatus of the present invention can be integrated into an intelligent remote terminal unit. This unit exercises motor control functions to include pump off/gas lock control and has the additional capabilities of monitoring ESP operation, storing operation data, and communication with a ¢central computer.

Having thus generally described the apparatus and method of the present invention, as well as its numerous advantages over the art, the following is a more detailed description of a preferred embodiment thereof given in accordance with specific reference to the drawings.

Step 1: sample current continuously (analog to digital conversion) every .25 second. Step 2: start controller when current exceeds $\frac{1}{2}$ amp (occurs when ESP is started). Step 3: start controller functions when the current spike on ESP start is over. Step 4: take the most recent sample of current and store it in the first position of the data array for use later in the controller computations. Step 5: after the ESP is started, begin calculations only after the date array is full (6 seconds of current samples). Step 6: calculate the most recent one second average of current by averaging the first four values in the data array. Step 7: if the pump off counter is not equal to zero, then the last calculated difference was more than a 5% drop, indicating that the ESP already has gas in it and may be pumped off. Step 8: if the ESP is not already at potential pump off, calculate the normal previous

5-second average of current by averaging the last 20 samples in the date array. Step 9: if the ESP is already at potential pump off, do not recalculate the previous 5-second average of current. Use the previous average of current calculated when current first dropped in order to compare the most recent current to its original level. Step 10: subtract the most recent 1-second average from the previous 5-second average of current. Step 11: if the calculated difference is greater than a 5% drop, then gas has entered the pump and the ESP is potentially pumped off. Step 12: shut the ESP off in non-gassy pumping conditions since a current drop greater than 5% will only occur at pump off. Step 13: count the length of time the ESP is in a potential pump off condition (one count equals 25 seconds). Step 14: in gassy pumping conditions, the ESP has pumped off and is shut down if current does not return to its original 5-second average (before current drop occurred) in 10 seconds or less. Step 15: prepare the date array for the next current sample by bumping the data in the array down one. This effectively erases the oldest current sample and makes room for the next current sample to be added to the top of the array (first position).

While the above description is primarily directed to detecting electrical pump motor underload which is indicative of gas lock or pump off, the basic invention is more broadly drawn to methods and related apparatus for monitoring and controlling pump operation by measuring changes in pump input power. This is done (a) in pumps with electric motor drives by measuring motor load and comparing present motor loads to previous motor loads, (b) in pumps with hydraulic motor drives by measuring hydraulic power consumed (input pressure and flow rate - output pressure and flow rate) and, as above, comparing present motor loads to previous motor loads. Potential pump/motor combinations include (1) centrifugal pump with electric motor drive, (2) centrifugal pump with hydraulic motor drive, (3) positive displacement pump with electric motor drive, (4) positive displacement pump with hydraulic motor drive.

The foregoing description of the invention is merely intended to be explanatory thereof, and various changes in the details of the described method and apparatus may be made within the scope of the appended claims without departing from the spirit of the invention.

The claims defining the invention are as follows:

1. A method for controlling a pump comprising the steps of:

   (a) determining pump power consumption at timed intervals;

   (b) obtaining a recent pump motor power consumption from the determinations;

   (c) obtaining a previous pump motor power consumption from the determinations;

   (d) deriving the difference between the recent pump motor power consumption and the previous pump motor power consumption;

   (e) denoting the difference as differential pump fluid power output; and

   (f) shutting the pump down when the differential pump fluid power output exceeds a predetermined amount for a predetermined length of time.

2. A method for controlling a pump driven by an electric motor comprising the steps of:

   (a) determining motor loads at times intervals;

   (b) obtaining a recent motor load from the determinations;

   (c) obtaining a previous motor load from the determinations;

   (d) deriving the difference between the recent motor load and the previous motor load;

   (e) denoting the difference as indicative of pump motor underload when the difference exceeds a predetermined quantity: and

   (f) shutting the pump motor down when motor underload is detected.

3. The method of claim 2, wherein step (f) comprises determining the length of time during which the underload is detected, and shutting the pump down if this time exceeds a predetermined length of time.

4. The method of claim 2 or claim 3 wherein the motor loads are determined from apparent power utilised by the pump motor.

5. The method of claim 2 or claim 3 wherein the motor loads are determined from actual power utilised by the pump motor.

6. The method of claim 2 or claim 3 wherein the motor loads are determined from reactive power utilised by the pump motor.

AUSTRALIAN PATENT OFFICE

KWK:855y

7. The method of claim 2 or claim 3 wherein the motor loads are determined from current utilised by the pump motor.

8. The method of claim 7, wherein voltage accompanying the current is utilised to screen out corresponding current fluctuations which are the result of voltage spikes or sags and not pump off or gas locking.

9. The method of any one of claims 2 to 8 wherein the recent motor load is an average of determinations computed over a selected time interval, and wherein also the previous motor load is an average of determinations computed over a selected time interval.

10. The method of any one of claims 2 to 9 wherein step (d) is based on a computation of the differential of motor load with respect to time.

11. The method of any one of claims 2 to 9 wherein step (d) is based on integration of motor load with respect to time.

12. The method of any one of claims 2 to 9 wherein step (d) is based on statistical analysis.

13. An apparatus for controlling a pump comprising means for determining pump power consumption at timed intervals, means for obtaining a recent pump motor power consumption from the determinations, means for obtaining a previous pump motor power consumption from the determinations, means for deriving the difference between the recent pump motor power consumption and the previous pump motor power consumption, means for denoting the difference as indicative of differential pump fluid power output when the difference exceeds a predetermined quantity, and means for shutting the pump motor down when the difference exceeds a predetermined quantity.

14. An apparatus for controlling a pump driven by an electrical pump motor, the apparatus comprising means for determining motor loads at times intervals, means for obtaining a recent motor load from the determinations, means for obtaining a previous motor load from the determinations, means for deriving the difference between steps the recent motor load and the previous motor load, means for denoting the difference as indicative of pump motor underload when the difference exceeds a predetermined quantity, and means for shutting the pump motor down when motor underload is detected.

15. A method for controlling a pump, substantially as hereinbefore described with reference to any one of the Examples.

KWK:853y

AUSTRALIAN PATENT OFFICE

16. An apparatus for controlling a pump, substantially as hereinbefore described with reference to any one of the accompanying drawings.

DATED this TWENTY-SEVENTH day of JUNE 1990
Shell Internationale Research Maatschappij B.V.

Patent Attorneys for the Applicant
SPRUSON & FERGUSON

KWK:855y

18 7 88 19175

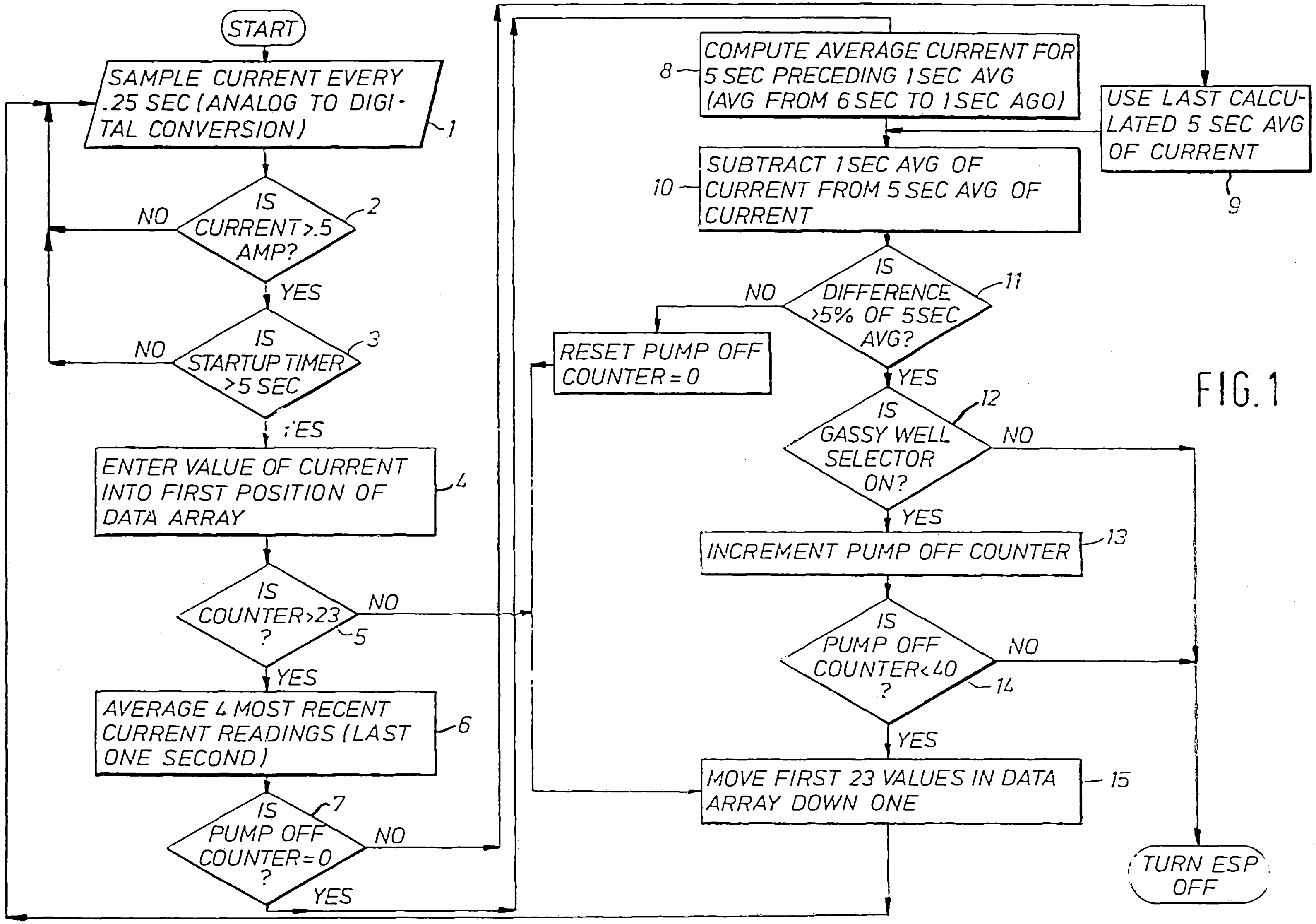

FIG.1

19 175/88