(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 253 717 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
04.10.2023 Bulletin 2023/40

(21) Application number: **22165676.2**

(22) Date of filing: **30.03.2022**

(51) International Patent Classification (IPC):
E21B 19/20 *(2006.01)* ***E21B 21/08*** *(2006.01)*
E21B 44/00 *(2006.01)*

(52) Cooperative Patent Classification (CPC):
E21B 19/20; E21B 19/00; E21B 21/01; E21B 21/08; E21B 2200/22

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

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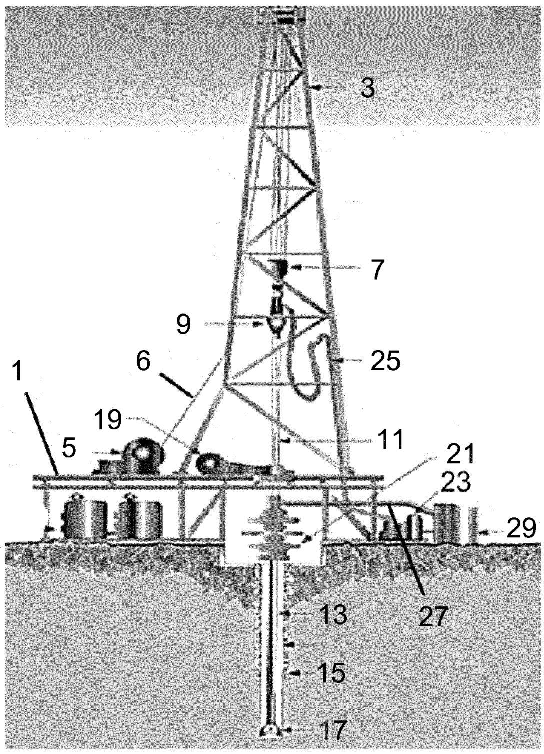
(54) **METHOD OF DETERMINING THE STATE OF A DRILLING RIG**

(57) The present invention relates to a machine-learning method for determining the state of a drilling rig, said method comprising in particular using the vertical position (E) of a travelling block (7) as an input to the machine-learning algorithm.

[Fig. 1]



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Description

FIELD OF THE INVENTION

[0001] This patent application relates to the field of drilling, in particular for extracting hydrocarbons such as oil, gas or thermal energy from the ground, both offshore and onshore.

BACKGROUND OF THE INVENTION

[0002] As known in itself, before exploiting a hydrocarbon deposit, it is advisable to carry out one or more drilling operations from a drilling rig located above the deposit.

[0003] The purpose of these drilling operations is to explore and then exploit the deposit.

[0004] Conventionally, the drilling operation involves the end-to-end assembly of drill pipes called a drill string and a drill bit located at the end of the drill string, the drill string thus assembled being rotated so that the bit drills out the rocks crossed to create a conduit called wellbore to the hydrocarbon deposit.

[0005] During the wellbore construction process, the drill string is introduced into and extracted from the wellbore several times, and the drill pipes are respectively assembled and disassembled one after the other during these operations.

[0006] During all these operations, a drilling fluid is injected into the drilling string, so as to lubricate the drill bit and convey the drilled rock cuttings up to the surface.

[0007] During the operation of such a drilling rig, it is important to monitor the wellbore for its status and condition at all times during the operations that are being carried out, in order to provide operators with relevant information enabling them to make the appropriate decisions.

[0008] For example, the various operations that may be in progress sequentially or simultaneously are the assembly or disassembly of drilling pipes, the "tripping-in" (descent) or "tripping-out" (ascent) of the drilling string, the stopping or start-up of injection of drilling fluid inside the drilling string, injecting of drilling fluid into the wellbore, etc.

[0009] The "rig state" can be defined by the operations or activity that are in progress.

[0010] Several methods exist in prior art for breaking the workflow into various states such as drilling, tripping-in, tripping-out, etc.

[0011] Most of the existing methods implemented are deterministic in nature and derived from specific data sources and multiple measurement points such as block position, hook load, flow in, pump pressure, torque/RPM, on-bottom status, and in-slip - out-of-slip status (in-slip status implies that rotary slips are put into rotary hole and drill string load is borne by them, which implies the drill string load is not borne by the hook. The out-of-slip status implies that there is no rotary slip in rotary hole, the drill string is attached to the hook, and its load is borne by the hook).

[0012] These data sources are derived from various sensors that are installed on a drilling rig. However, due to the limitation in some of these measurements, the computation has restricted value in certain situations. For example, when the drill string is shallow, the load of the drill string is not large enough to discriminate the load of the travelling block. This results in erroneous readings, or it may result in the lack of accuracy such as when detecting the slip status. As the rig state requires an accurate identification of in-slip status, the computation derived from rig state becomes unreliable with introduction of errors.

[0013] Typically, the rig state detection for tripping-in and tripping-out is based on a logic of using the computed bit depth and computed total depth. When the bit depth is less than the total depth by a certain amount, and based on the direction of change for the bit depth, it is qualified as tripping-out or tripping-in. Typically, this computation stops functioning at shallower depth due to limitation in the existing algorithm and the bit depth computation is managed manually.

[0014] Another aspect in drilling rigs, is that drilling fluid level in a circulating system is very dynamic during a wellbore construction process. The accurate measurement of fluid level in the fluid tank is used as a key monitoring element to understand the fluid return behavior from the well, which in turn indicates the wellbore safety, whilst the wellbore is being drilled. Since the activities of treating the drilling fluid are taking place concurrently, the status of the fluid level evolves and hence only a gross plan exists in terms of volume present in the tanks. This dynamic activity makes the monitoring of the fluid a tedious task as it involves several communications with the mud tank supervisor to understand the changes taking place in the tank volume.

SUMMARY OF THE INVENTION

[0015] This invention describes the use of an algorithm, machine-learning based, to improve and minimize the errors introduced due to the limitations of current techniques.

[0016] Block position, one of the critical parameters applied in rig state computation, is monitored as a single source of data to accurately detect rig state as well as to detect potential measurement issues from the sensor and sensor data transfer functions.

[0017] Furthermore, this invention also monitors discrepancy in depth computation during real-time operation that results in allowing for better data quality control during the course of drilling.

[0018] With a new method used for the computation of a rig state, in addition to existing algorithms, this invention helps to corroborate the rig state detection thereby enabling an innovative monitoring solution to automate the monitoring functionality of a wellbore construction process and complementing the human vigilance currently in use.

[0019] The invention is defined by appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] Other characteristics and advantages of the invention will emerge from reading the following description, with reference to the annexed figures, which illustrate:

[Fig. 1]: a drilling rig implementing the method according to the invention,

[Fig. 2]: the main steps of a tripping-in process on a drilling rig,

[Fig. 3]: a mast with its hoisting block and hook carrying a drilling string, with tripping-in and tripping-out speed profiles,

[Fig. 4]: distribution curves of the speed of travelling block over the distance of the travelling block from the rig floor, for different loads of this block,

[Fig. 5]: a curve indicating the distance of the travelling block from the rig floor over time, with a sudden change of a maximum value of this height, together with a figure illustrating the maxima and minima positions of the travelling block,

[Fig. 6]: a curve indicating the distance of the travelling block from the rig floor over time, with a drift of the minimum values of this distance,

[Fig. 7]: a curve indicating the distance of the travelling block from the rig floor over time, with different durations separating on the one hand consecutive minimum and maximum values, and on the other hand consecutive maximum and minimum values,

[Fig. 8]: a curve indicating the distance of the travelling block from the rig floor over time, with two different consecutive maximum heights, and related views showing the travelling block and drill string positions corresponding to different parts of the curve,

[Fig. 9]: a curve indicating the volume of a drilling fluid inside the trip tank, along with a cumulative filtered delta volume, and

[Fig 10]: a diagram showing the machine-learning process for determining drilling fluid level in trip tank.

DETAILED DESCRIPTION OF THE INVENTION

[0021] For greater clarity, identical or similar elements are identified by identical or similar reference signs on all figures.

[0022] We now refer to Figure 1, on which is represented a drilling rig according to the invention.

[0023] This drilling rig has a rig floor 1, on which a mast 3 is mounted.

[0024] A motorized drum 5 on which a drill line 6 is wound makes it possible to raise or lower a travelling block 7 inside the mast 3.

[0025] A hook 9 is suspended from this travelling block 7; this hook 9 can itself cooperate with drilling pipes 11 that are assembled end-to-end to make a drilling string 13 to drill a wellbore 15 with an end forming a bit 17.

[0026] A rotary drive system 19 of the drill string makes it possible to rotate the drilling string 13 and the bit 17 inside the wellbore 15, and thus drill the rocks and allow the drilling of the wellbore 15.

[0027] A blow-out preventer 21 closes the wellbore 15.

[0028] The drilling rig also includes a drilling fluid injection circuit, including a drilling fluid tank 23, a flexible drilling fluid supply pipe 25 at the top of the drilling string, a drilling fluid return pipe 27 and a trip tank 29.

[0029] This closed fluid injection circuit makes it possible to exit the drill bit 17 entering the annulus between the drill string 13 and wellbore 15, making it possible in particular to lubricate the wellbore 15 and evacuate the rock cuttings drilled by the drill bit 17.

[0030] Typical drilling operations can be viewed on drawings 2-1 to 2-7 of figure 2.

[0031] On 2-1, the travelling block 7 is at its highest position on the mast 3, and a set of 3 drilling pipes 11 (called "a stand") is waiting on a side rack on the rig floor 1.

[0032] On 2-2, the stand of drill pipes 11 is picked by the hook 9 and conducted at the center of the mast 3, in order to be connected to the drill string 13 which extends into the wellbore 15.

[0033] On 2-3, 2-4, 2-5, the travelling block is progressively lowered while the drive system 19 is rotating, thereby allowing the bit 17 located at the extremity of the drill string 13 to drill the rocks.

[0034] On 2-6, once the travelling block 7 has reached its lowest position, the hook 9 is disconnected from the drill string 13.

[0035] On 2-7, the travelling block is being raised towards its highest position in the mast 3, ready for handling the next pipe stand.

Determining the rig state of tripping-in or tripping-out

[0036] Digital classification of the activity on the rig, termed as rig state, is an essential element in controlling the sequence of the process in a wellbore construction workflow. Traditionally the rig state classification is achieved using a sensor fusion method; the hook load and block position being the most important of those measurements.

[0037] In this invention, the pattern of the block movement is used in determining the activity that the travelling block 7 is doing in terms of conveying items into the wellbore 15. This estimation is done by using the first order distribution of the block position as it traverses up and down the mast. The first order distribution is given by the following equation:

$$f(E') = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-\frac{(E'-\mu)^2}{2\sigma^2}}$$

Where E' is the first derivative of the change in travelling block elevation

[0038] The travelling block position going from rig floor 1 up the mast 3 is compared with the distribution of the first derivative of block position.

[0039] As can be seen on figure 3, the travelling block speed over its vertical position in the mast 3, illustrated by curves 3-1 and 3-2 respectively for ascending and descending movement, has in fact a substantially Gaussian distribution.

[0040] Depending on the mass carried by the block 7, the standard deviation of the first derivative is directly proportional to the load carried:

$$(\sigma_{E'}) \propto l$$

Where:

l is the load carried by the travelling block 7,

$\sigma_{E'}$ is the standard deviation of the block position first derivative.

[0041] As the load reduces, the shape of the normal distribution of the first derivative of block position keeps getting narrower with the standard distribution getting closer to the central tendency (μ).

[0042] For example, if we consider tripping-out the drill string out of the wellbore 15, the distribution function will vary as per one of curves C1 to C3 on figure 4 while the travelling block 7 moves up the mast pulling the drill string with it (C1: high load, C2: moderate load, C3: low load).

[0043] On the other hand, when the travelling block 7 travels down the mast 3 without any drill string, its distribution function will trace curve C4 on figure 4.

[0044] By comparing the density function between the block 7 travelling up the mast 3 and the block 7 coming down the mast 3, the direction the work done by the hoisting system in moving the drill string 13 can be estimated.

[0045] The rig state is compared between the up movement of the travelling block 7 and down movement of the travelling block 7 by taking the first derivative of the position to determine the rig state as "tripping-out". During the "tripping-in" process, the inverse of the density function is observed.

Maxima and minima determination

[0046] In one embodiment of this invention, the maximum and the minimum position of the travelling block 7 is computed using a maxima and minima detection machine learning algorithm.

[0047] In this algorithm, a cluster of points is selected based on the following criterion: change in the direction of the measured value by a qualifying set of points, mean distribution of the measurement within the qualified distribution of points and maximum and minimum points within the set.

[0048] The maximum value within a given set of data points is denoted by:

$$Maxima(x) = x|f(x): x = 1 \rightarrow n \quad \geq f(y)$$

[0049] And the minima are:

$$Minima(x) = x|f(x): x = 1 \rightarrow n \quad \leq f(y)$$

[0050] A sliding window is set to sub-sample the block position with respect to time and the Maxima and Minima (f(x)) is computed over the sub-sampling interval. The output of the function is then evaluated to identify if the given data set is static or moving. In case of moving, the maxima and minima is determined.

Sudden change of maxima and/or minima

[0051] Within the above-mentioned machine learning algorithm, the successive maxima points and the minima points are compared to give one of the following outputs:

- no change or static,
- sudden increase in the value, based on number of windows before a change is established,
- sudden decrease, based on number of windowed data processed.

[0052] An example of the use of the maxima and minima detection on block positions in data monitoring workflow is as follows.

[0053] During tripping operations, rotating the break is a process where a pipe 11 is removed from the set of pipes 13. This helps every other pipe connection to be opened and greased. This is an important operation for the health of the pipe threads. Laying down of the pipe 11 is normally a partially planned activity, however the index of the pipe to be laid down is not determined. By detecting the sudden change in the position of the block 7, the algorithm detects the time of such an activity and then attributes the time to the pipe index.

[0054] Annexed figure 5 illustrates a set of maxima positions M and minima positions m of block 7 over time, with a sudden decrease D of one of maxima positions.

[0055] In prior art, real-time monitoring of block position involves a supervisor to review the block position of data for variation which is a very time-consuming activity.

[0056] In the present invention, with the ability to detect sudden changes, the system sends a notification to the decision makers thereby significantly reducing the workload of the operator identifying such occurrences.

Trending the minima

[0057] Trending the minima, especially closer to the rig floor 1, helps identify inconsistencies with the sensor computing the block position.

[0058] In the normal course of operation, block position is an inferred measurement that is derived from the movement of draw works that raises or lowers the block 7 via the drill line 6. The sensor, an encoder is placed on the axis of the drum 5 that measures the rotation of the drum 5. The diameter of the drum is known and the amount of drill line 6 that paid out from the drum is computed to determine the position of the block 7. Bad installation of the sensor or vibration caused due to the rotational speed of the drum 5 results in a spurious signal that may impact the transfer function between rotation and travelling block position on the mast 3.

[0059] As illustrated on figure 6, by trending the successive minima m, the algorithm establishes whether the values are trending, or the values are random.

[0060] During normal operation, the successive minima are typically around 1 meter +/- 0,3 meter.

[0061] Trending here may mean measuring the difference between two successive minima measurements and compute the delta with the median or measure the drift in the minima by calculating the best fit trend between the minima and compute the resultant slope S, as illustrated on figure 6.

Computing the time delta

[0062] In another embodiment of the invention, maxima and minima detection is used to compute the time delta between two consecutives maxima or delta time between a maximum and minimum.

[0063] In this embodiment, the travelling block position and the associated time of occurrence is recorded and then compared to the next occurrence of maximum or minimum. A traveling block 7 pulling out a drill string 13 from the wellbore 15 will be slower to travel compared to a free block 7 due to the load as well as to protect the wellbore 15.

[0064] Thus, as illustrated by figure 7, by taking the time delta Δt during the upward movement and the time delta $\Delta t1$ during the downward movement of the travelling block 7, the larger delta time will indicate the direction of the drill string movement.

[0065] Travelling block velocity reaches a maximum value quickly when there is no drill string hanging from the travelling block 7, Δt will be small.

[0066] Travelling block velocity gradually increases when there is load hanging on travelling block 7. Hence, $\Delta t1$ will be larger.

Computing of ratio of momentum

[0067] In another embodiment, the ratio of momentum is computed to determine direction of drill string 13, whether it is added into the wellbore 15 or is being removed from the wellbore.

[0068] Linear momentum of a travelling body is given by:

$$\frac{p_u}{p_d} = R_{mud} x \left(\frac{R_{sud}}{R_{tdu}}\right)$$

Where:

p_u is momentum of the block 7 going up,

p_d is momentum of the block 7 going down,

R_{mud} is ratio of mass going up to mass going down,

R_{sud} is ratio of distance travelled going up to distance travelled going down, ratio of travel distance up to travel distance down,

R_{tdu} is time taken to cover the travel distance going down to time taken for travelling the distance going up.

[0069] Depending on the ratio of $\left(\frac{p_u}{p_d}\right)$, the direction of the travelling block 7 during tripping operation may be determined.

[0070] If the ratio $\left(\frac{p_u}{p_d}\right)$ shows an increase, then the operation is tripping-out whilst a decrease in the ratio of $\left(\frac{p_u}{p_d}\right)$ indicates tripping-in.

Comparison between maxima

[0071] In another embodiment the distance traversed for the first maxima is compared to the second maxima within a stipulated time "t."

[0072] During the pipe connection activity, the travelling block 7 requires to be raised to pick up a new pipe 11 and place it above the pipe stickup.

[0073] This is illustrated by curve 8-0 of figure 8, which represents positions 1 to 8 of the travelling block 7 over time, during an operation of pipe connection.

[0074] Corresponding rig statuses are illustrated respectively on drawings 8-1 to 8-8 of figure 8.

[0075] On drawing 8-1, block 7 is in lower position.

[0076] On drawing 8-2, block 7 is being raised towards its upper position.

[0077] On drawing 8-3, block 7 has reached its upper position.

[0078] On drawing 8-4, block 7 is pricking a set of drilling pipes 11 (called a stand), for example 3 drilling pipes here, from the adjacent drilling pipe rack 30. In order to connect the stand to the previous one, the new setup of pipes has to be moved up by around 1 meter.

[0079] On drawing 8-5, once the new stand is connected, the entire drill string 15 is moved up to disengage the slips 31, *i.e.* the equipment that was previously placed in order to block the axial movement of the drill string 15 on the rig floor 1.

[0080] On drawings 8-6 to 8-8, the block 7 is lowered toward its minimal height, allowing the drill string 13 to trip-in the wellbore 15.

[0081] The distance ΔS between points 4 and 5 of curve 8-0 (2 maxima) is computed. If the first maxima distance is higher than the second maxima distance, then the drill string is conveyed into the wellbore 15 while the inverse maxima distance indicate that the drill string is coming out of the wellbore 15.

$$\Delta S = S_{mt\mathbf{1}} - S_{mt2} \ (\Delta \text{ t} \leq \text{t})$$

$$t_1 - t_2 \leq t$$

Where:

ΔS is delta distance between maxima 1 and maxima 2,
S_{mt1} is distance of maxima at time t_1,
S_{mt2} is distance of maxima at time t_2.

[0082] Using this embodiment of the invention, tracking depth at shallow distance can be achieved where it is difficult to discriminate when the drill string 13 is out-of-slip or in-slip by coupling this algorithm with a state machine.

<u>Filtering the trip tank volume</u>

[0083] In another embodiment of this invention, the maxima and minima algorithm is used to filter the value of the trip tank 29 to generate an automated "fill up" or "returns" during tripping operation.

[0084] In normal operations, one of the important parameters with respect to wellbore safety is to maintain a constant bottom hole pressure in the wellbore 15.

[0085] This is achieved classically by maintaining the wellbore 15 full of drilling fluid.

[0086] During a tripping-out activity, the drill string 13 is removed from the wellbore 15 in segments of drill pipes 11. As each segment is withdrawn from the wellbore 15, the volume of steel removed must be replaced by the drilling fluid in the wellbore 15 to ensure wellbore safety. To maintain the fluid level in the wellbore 15, drilling fluid is pumped from the trip tank 29 equal to the steel volume removed from the wellbore.

[0087] As can be seen on figure 9, during each withdrawal of a drill pipe 11, the trip pump is started, thereby generating a descending series of minima M_i of drilling fluid volume and a maxima M_a when the trip pump is stopped inside trip tank 29.

[0088] As the fluid is being pumped from the trip tank 29, the trip pump adds an artifact to the fluid level in the trip tank 29 that makes the determination of accurate displacement of fluid volume difficult.

[0089] By detecting successive maxima M_a (see figure 9) in the present invention embodiment, the artifact created by the trip pump is removed by detecting the maximum level in the trip tank 29 in the same state over successive fill ups. This enables accurate tracking of the drilling fluid volume.

[0090] The change of volume may be detected using successive minima M_i (see figure 9) with the same accuracy.

[0091] Any sudden variation (SV on figure 9) caused in the trip tank level during the tripping operation - for example because of transfer or drilling fluid to trip tank 29 - is excluded from the calculation by applying low-pass volume data filter allowing the generation of an automated and reliable trip sheet.

[0092] The computations are done as follows:

$$\Delta V_{ma} = M_{a2} - M_{a1}$$

$$\Delta V_{mi} = M_{i2} - M_{i1}$$

$$Cum\,\Delta V_{ma} = \sum_{i=0}^{n} \Delta V_{ma}$$

$$Cum\,\Delta V_{mi} = \sum_{i=0}^{n} \Delta V_{mi}$$

$$fc\,\Delta V_{ma} = Cum\,\Delta V_{ma} \leq V\ \pm e$$

$$fc\,\Delta V_{mi} = Cum\,\Delta V_{mi} \leq V\ \pm e$$

Where:

M_{a1} & M_{a2} are consecutive maxima of trip tank volume,
ΔV_{ma} is delta volume maxima,
M_{i1} & M_{i2} are consecutive minima of tank volume,
$\Delta V_{mi}$is delta volume minima,
$fc\ \Delta V_{ma}$ & $fc\ \Delta V_{mi}$ is filtered cumulative delta volume (curve $fc\ \Delta V$ on figure 9),
e is standard error.

State of fluid level in trip tank

[0093] As discussed in the previous section, one of the key criteria to ensure wellbore safety is to monitor the level of drilling fluid in the circulating system. The circulating system consists of several fluid tanks 23 used for both taking the returns fluid from the wellbore 15 during the wellbore construction process as well as allowing the treated fluid to be pumped back into the wellbore 15.

[0094] Therefore, continuous monitoring of the fluid level in real-time for any variances is extremely important both, to attribute a reason for the change in the level of tanks, and to be assured of wellbore safety.

[0095] Whilst monitoring the fluid tanks 23 in real-time during the well-construction process, there is a communication protocol that mandates key stakeholders to be informed about any changes (pre-defined) in fluid levels.

[0096] Circulating system is very dynamic as it can change from being an offline volume of liquid state to being active state. An active state can arise through fluid transfer from another tank or potentially an unaccounted influx from the wellbore 15. In-between these states, there is a steady state that is determined by no change in volume.

[0097] Due to the dynamic nature of the fluid in the tanks 23, it is often very challenging to determine a reliable state of the tank level.

[0098] One embodiment of the invention exploits the curve fitting function as a series of polynomial equation that is used to fit the level change and determine the state of the tank. This machine learning approach determines the curve behavior between a linear fit and a polynomial fit and assigns the reasons for change.

[0099] As illustrated by the flow chart of figure 10, the instantiation of this technique is triggered by the change of state of the mud pumps: step 10-1 of figure 10. This change in state of the mud pumps may be determined by either a state engine like the rig state or directly by measuring the pump stroke rate or the flow from the mud pumps.

[0100] On instantiation, a time window is opened to sub-sample the time data for a pre-determined delta time (steps 10-2 and 10-3 of figure 10, corresponding respectively to pump state change from "off" to "on" and from "on" to "off"). The data points thus gathered is run through the machine learning algorithm (step 10-4: data pre-processing; step 10-5: running of the machine learning algorithm; step 10-6: generation of the machine learning output) to estimate the fit of the curve, and provide the operator with an information on the state of drilling fluid tank 23 (10-7: tank off-line; 10-8: tank in-line; 10-9: transfer of drilling fluid; 10-10: stable sate of fluid tank).

[0101] The linear fit for the data point cloud in the data slice is:

$$L_i = f(T_i, \beta) + er_i$$

Where:

L_i is the level of the tank of interest,
T_i is the time of sub-sampled data,
β is the fitting function,
er_i is the error margin.

[0102] For the polynomial fit:

$$Li = a_0 + a_n T^n \pm er_i$$

Where:

a_0 *to* a_n are the curve fitting parameters,
T^n is the nth point of level in the sequence of points of measurement.

[0103] By applying the process and function, an optimized curve fitting parameters are achieved for a given data slice. This optimized parameter is compared with the iterative output of the training set of data from specific tank with given cross-section, to achieve prediction on the state of the tank 23.

Determination of state of trip pump

[0104] In another embodiment of this invention, the trip tank state may be used to determine whether the trip pump is running or not. Since the trip activity is followed by drilling activity, the trip pump may be forgotten to be switched off.
[0105] Switching off a trip pump causes the level of the trip tank volume to go up. The above-mentioned tank state detection algorithm detects this change and can be used to validate the plan.

Detection of volume displacement during tripping operations

[0106] Another embodiment of trip tank volume management is to detect dynamically the volume displacement during tripping operations of the drill string 13 into or out of the wellbore 15.
[0107] As the drill string 13 is removed from the wellbore 15, its volume is replaced with mud volume from the trip tank 29 at the same rate as the drill string 15 is coming out. Conversely, when the drill string 13 is run into the wellbore 15, it displaces a volume of steel that is recovered in the trip tank 29:

$$\frac{d}{dt}V \propto \frac{d}{dt}BP$$

$$f(V') = k * f(E')$$

Where:

V' is the first derivative of trip tank volume,
E' is the first derivative of the travelling block elevation normalized for direction of movement,
k is the efficiency of the trip pump.

[0108] As results from above disclosure, the present invention provides for a rig monitoring method using machine learning, where different operation patterns are identified through a machine-learning process and used later for actual comparison with measured operational parameters.
[0109] Such comparison allows for classification of rig states.

Claims

1. Method of determining the state of a drilling rig, comprising:

    a) prior to operation of said drilling rig:

        - selecting at least one operational parameter (E) which is representative of the state of the drilling rig over a slice of time,
        - inputting said operational parameter in at least one machine-learning algorithm in order to generate a series of patterns overtime which are respectively characteristic of a series of states of the drilling rig,

    b) during operation of the drilling rig:

        - measuring said operational parameter (E) over a slice of time,
        - inputting said operational parameter in said algorithm,
        - comparing the pattern thus obtained with said series of patterns, and
        - deducting from said comparison the state of the drilling rig.

2. Method according to claim 1, wherein said operational parameter is the position (E) of the travelling block (7) of said drilling rig.

3. Method according to claim 2, wherein a normal distribution function of first derivative (E') of said position (E) is used for generating said patterns, allowing to determine tripping-in or tripping-out state and load carried by the travelling block (7).

4. Method according to claim 2 or 3, wherein a sudden decrease of a maximum height of said travelling block (7) is used for determining removal of a drilling pipe (11) from a set of drilling pipes.

5. Method according to any of claims 2 to 4, wherein a trend (S) in the successive minima (m) of the height of the travelling block is used for signaling a malfunction of a position sensor.

6. A method according to one of claims 2 to 5, wherein the travelling time of the travelling block (7) between its two extreme positions is compared for two consecutive travels and is used for deducing the direction of movement of the drilling string (13).

7. A method according to one of claims 2 to 6, wherein two consecutive maxima (M) of the height of the travelling block are compared for determining tripping-in or tripping-out state.

8. A method according to any one of the preceding claims, wherein said operational parameter comprises level of drilling fluid in a trip tank (29) and said machine-learning algorithm allows for determination of status of said trip tank (29), said status being selected from the group comprising off-line tank (10-7), in-line tank (10-8), transfer (10-9) and stable state (10-10).

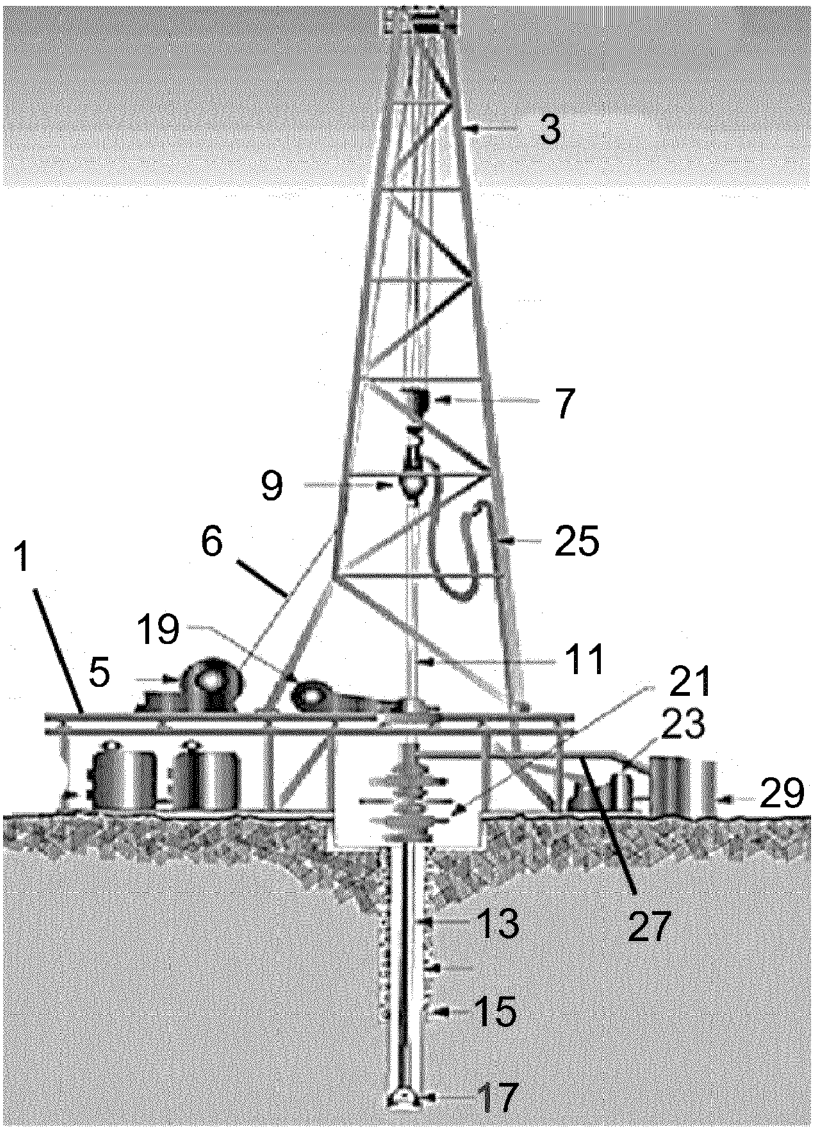
9. A method according to claim 8, wherein said algorithm comprises a curve fitting function.

10. A method according to claim 8 or 9, wherein the trip tank (29) state is used for determining the state of at least one drilling fluid pump.

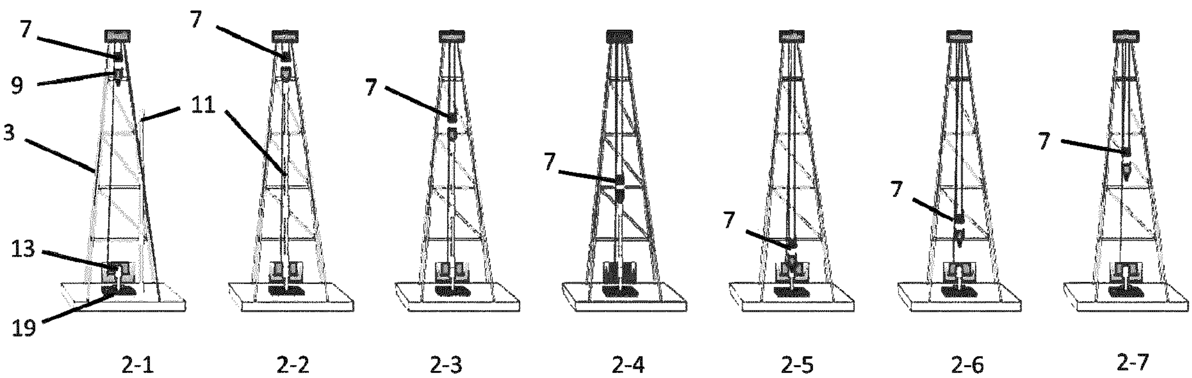
11. Product computer program, comprising a series of instructions for implementing a method according to any of the preceding claims.

12. Drilling installation, driven by a product according to claim 11.

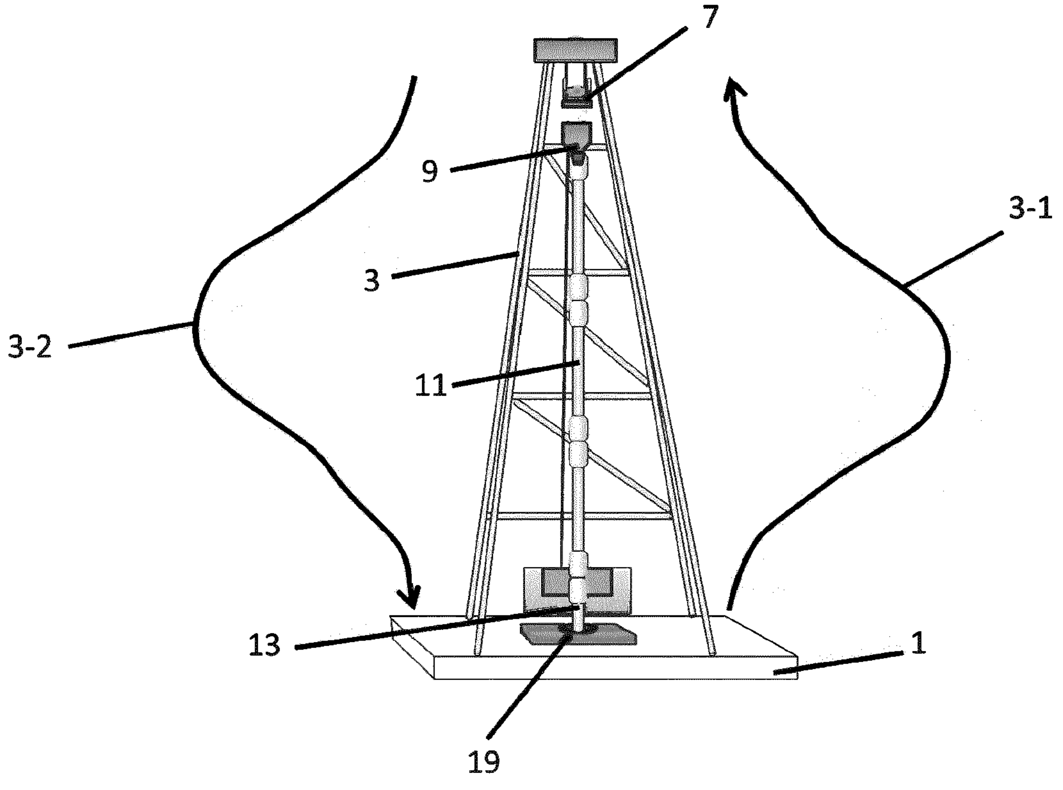
[Fig. 1]



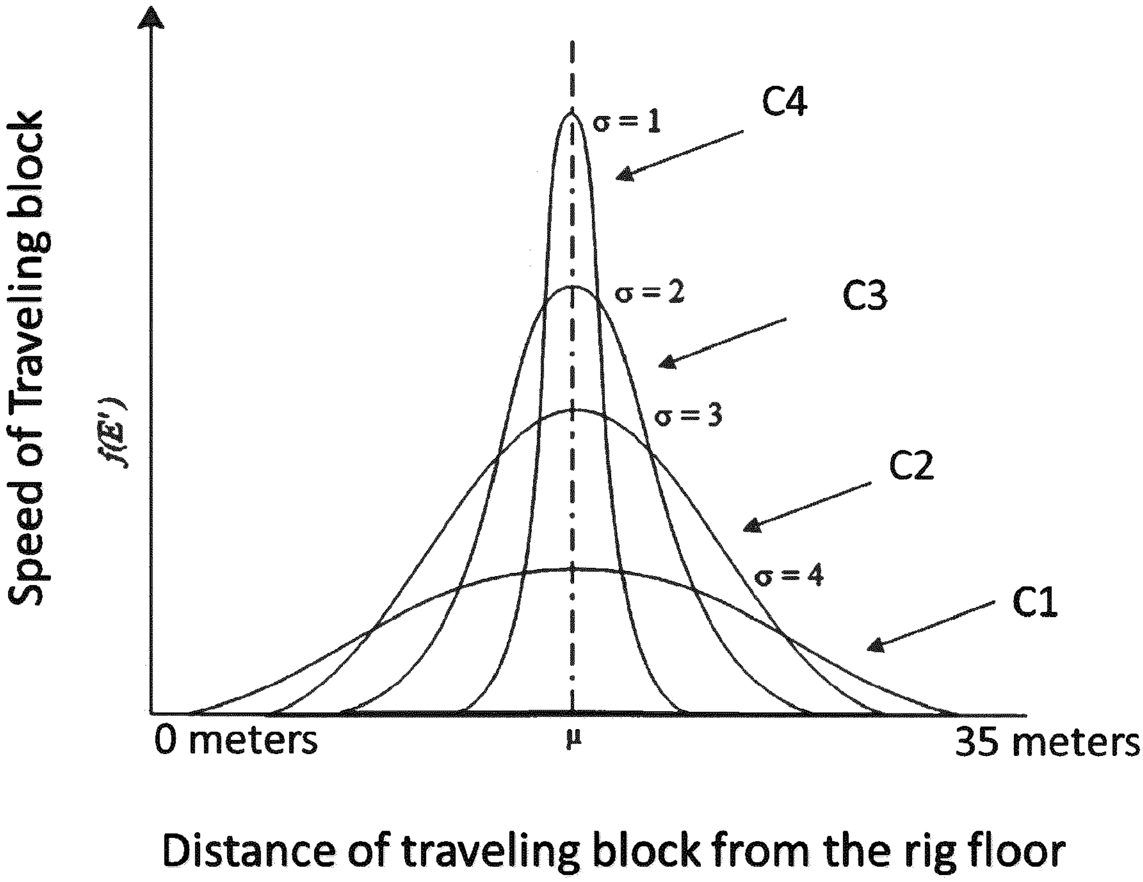
[Fig. 2]



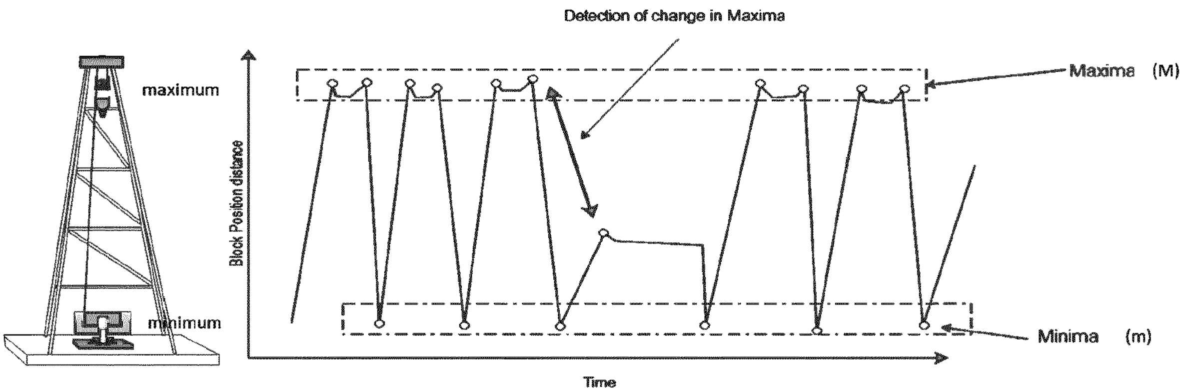
[Fig. 3]



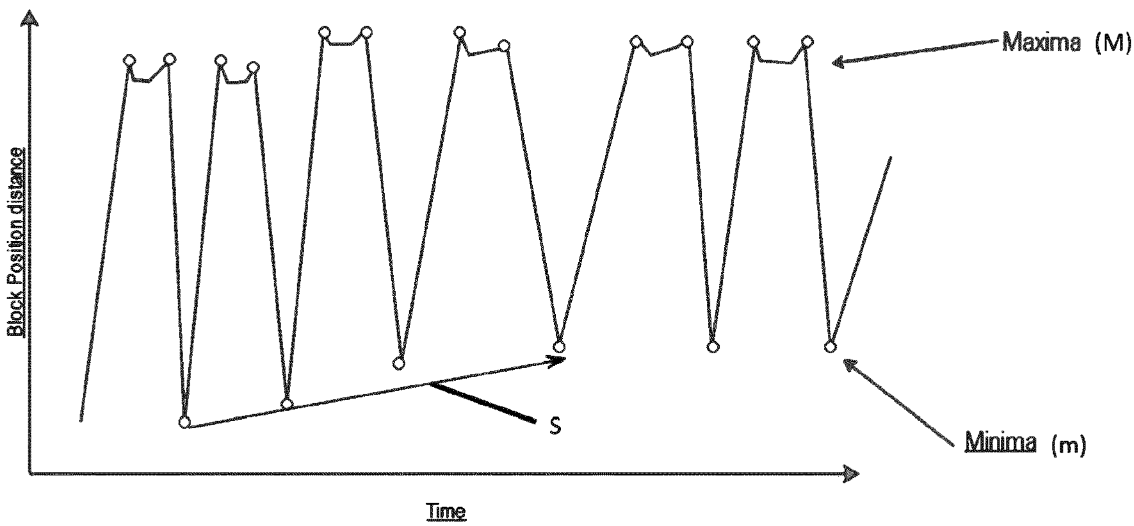
[Fig. 4]


Speed of Traveling block
f(E')
σ = 1
C4
σ = 2
C3
σ = 3
C2
σ = 4
C1
0 meters
μ
35 meters
Distance of traveling block from the rig floor

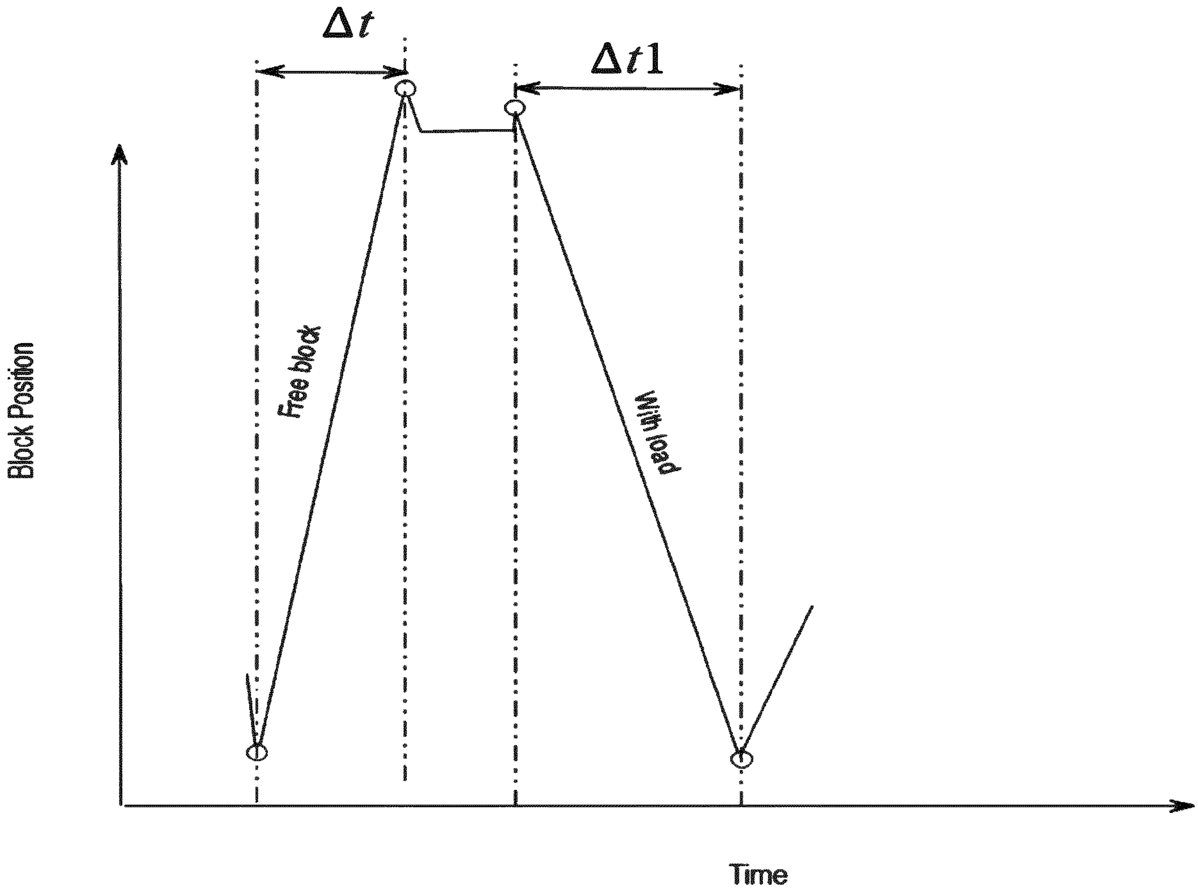
[Fig. 5]


Detection of change in Maxima
maximum
minimum
Block Position distance
Time
Maxima (M)
Minima (m)

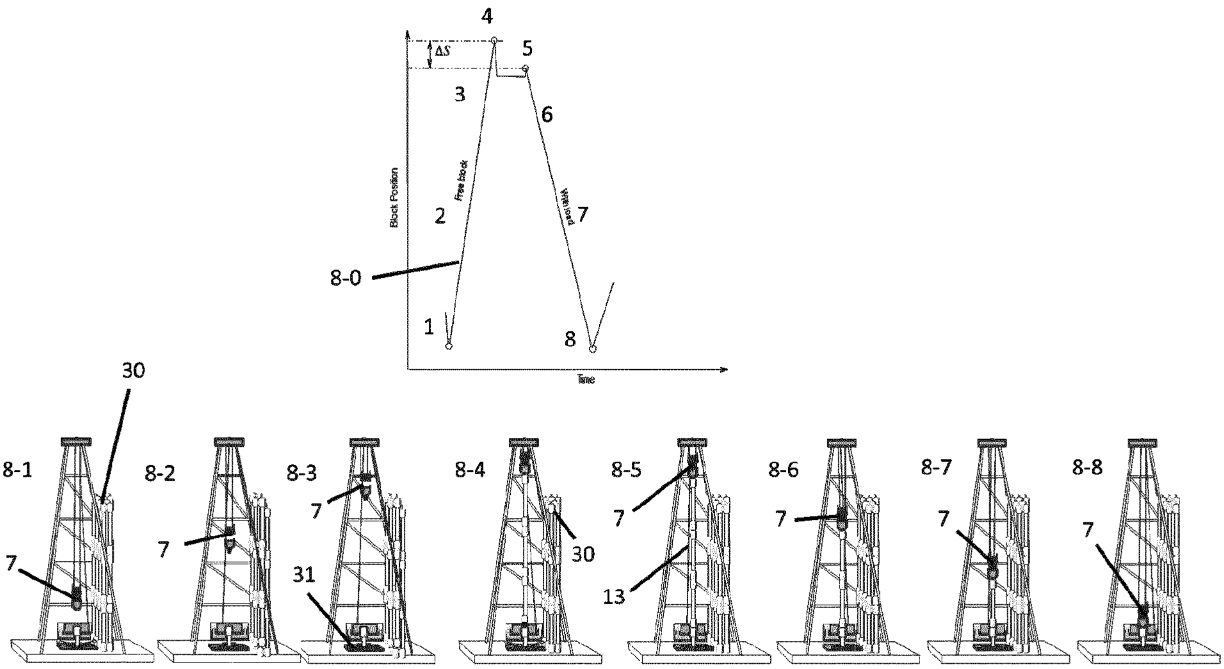
[Fig. 6]



[Fig. 7]

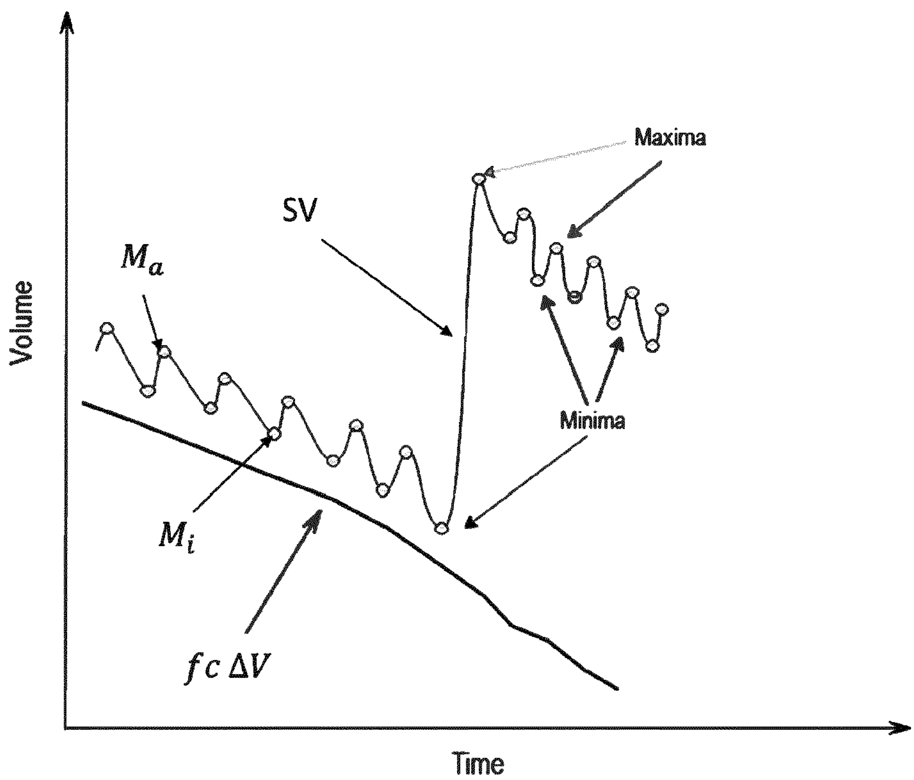


[Fig. 8]

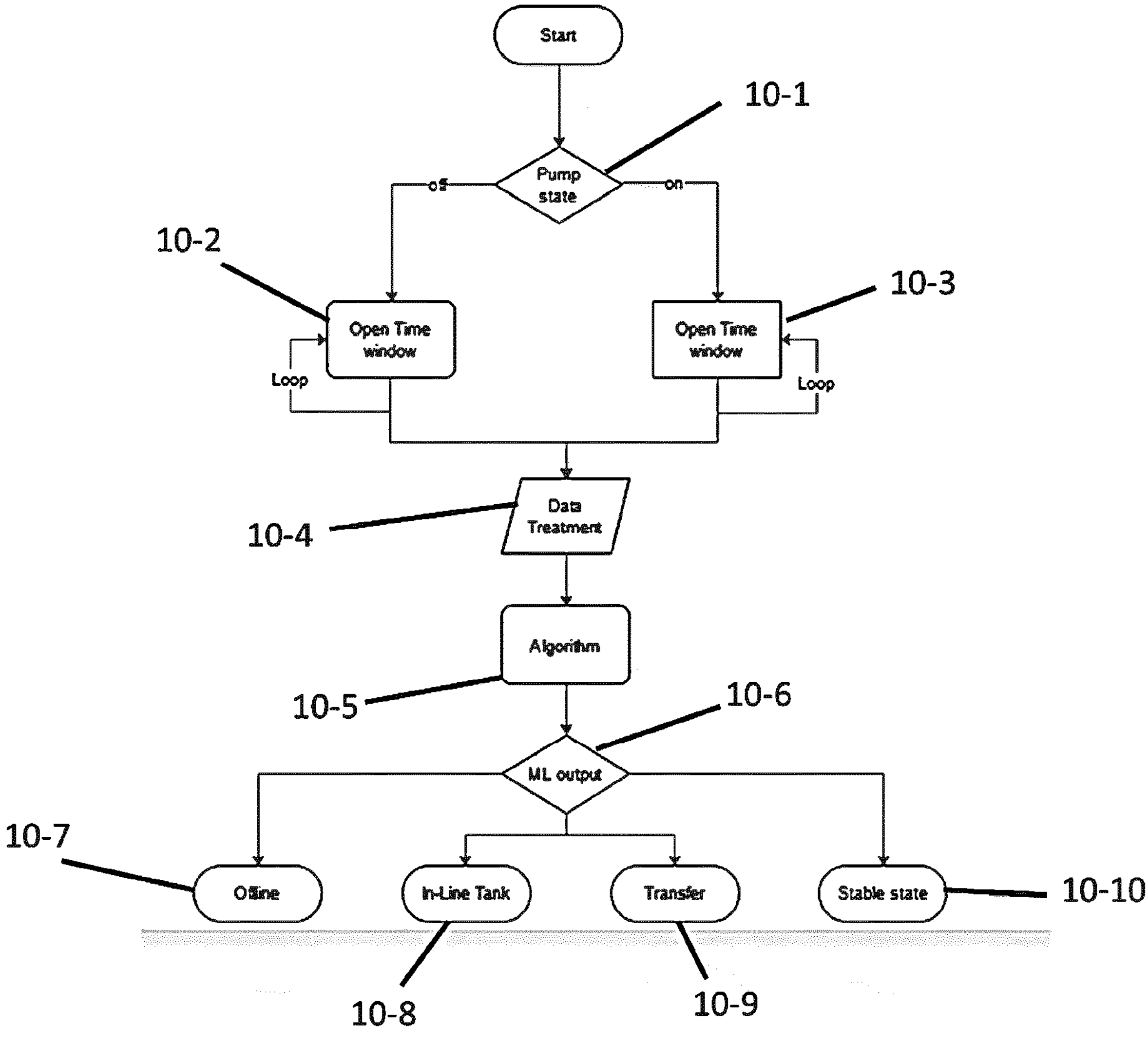


4
5
ΔS
3
6
Block Position
Free block
2
With load
7
8-0
1
8
Time
30
8-1
8-2
8-3
8-4
8-5
8-6
8-7
8-8
7
7
7
7
7
7
7
7
30
31
13

[Fig. 9]



[Fig. 10]


Start
10-1
Pump state
off
on
10-2
10-3
Open Time window
Open Time window
Loop
Loop
Data Treatment
10-4
Algorithm
10-5
10-6
ML output
10-7
Offline
In-Line Tank
Transfer
Stable state
10-10
10-8
10-9

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EUROPEAN SEARCH REPORT

Application Number
EP 22 16 5676

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A	* claim 1 *	1-10	

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			E21B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	10 November 2022	Ott, Stéphane

CATEGORY OF CITED DOCUMENTS

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