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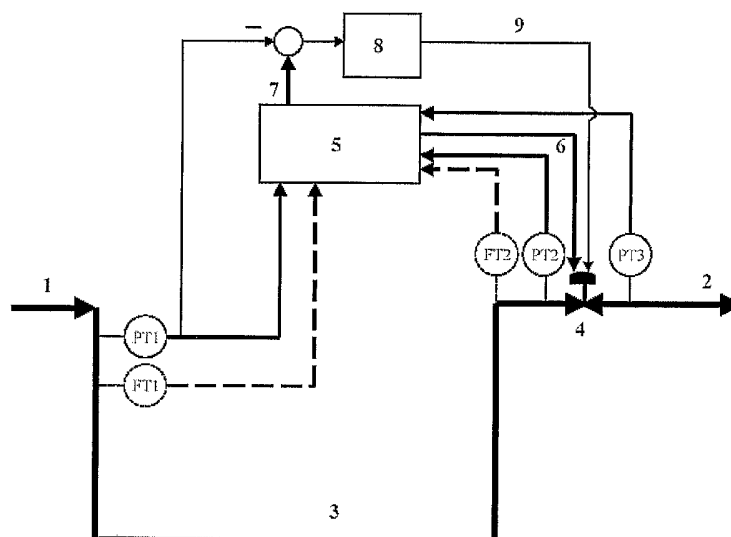
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(54) Title: A METHOD AND A SYSTEM FOR ENHANCED FLOW LINE CONTROL



(57) Abstract: The invention relates in a first aspect to a method for automatically controlling a flow in a flow line system including a flow line (3), a flow line inlet (1) and outlet (2), and a control valve (4) located in the flow line (3) at the outlet (2). The method includes the steps of: controlling the opening of the valve by means of a control unit (5) measuring or estimating an outlet flow rate (FT2), for example, from the flow line (3), and opening of the valve, determining if a sudden drop occurs in any of the measurements or estimates, deciding if a liquid blockage in the flow line is present or approaching, and if a liquid blockage is indicated as present or approaching, increasing the opening of the valve (4) by an amount determined by the measurements or estimates, inhibiting any further manipulation of the valve (4) before a non-zero time period has expired, and repeating the steps according to the above. The invention also relates to a corresponding system and a computer program product.



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

A METHOD AND A SYSTEM FOR ENHANCED FLOW LINE CONTROL

Field of Invention

The present invention relates to a method and system for
5 automatically controlling a flow in a flow line system,
said flow line system including a flow line inlet and
outlet, a control valve or choke located in the flow line
at the outlet, and a control unit controlling the opening
of the valve or choke. The present invention also relates
10 to a computer program product for executing one or more
steps of the method.

In a first aspect, the invention is used for avoiding
liquid blockages in flow line systems. Liquid blockages
15 causes flow line systems to be slugging, which is highly
undesirable from an operational point of view. In a
second aspect, the invention is used for providing a set
point to a control unit controlling the opening of the
valve or choke for enhanced control of the fluid flow in
20 the flow line. The invention may typically be applied in
the oil and gas production industry for enhanced control
of flow lines. Typical flow lines are pipelines, well
production lines (or wells), and risers.

25 Background

In oil and gas production systems, unstable flow in flow
lines might cause serious and troublesome operational
problems for the downstream receiving production facilities.
Typical flow lines are pipelines, wells, or risers. Common
30 forms of flow variations are slug flow in multiphase
pipelines and casing heading in gas lifted oil wells. In
both cases the liquid flows intermittently along the pipe in
a concentrated mass, called a slug. The unstable behaviour
of slug flow and casing heading has a negative impact on the
35 operation of oil and gas production system, such as offshore
facilities. Severe slugging can even cause platform trips
and plant shutdown. More frequently, the large and rapid

flow variations cause unwanted flaring and limit the operating capacity in the separation and compression units. This reduction is due to the need for larger operating margins for both separation (to meet the product
5 specifications) and compression (to ensure safe operation with minimum flaring). Backing off from the plant's optimal operating point results in reduced throughput.

Three approaches are conventionally practiced to manage the instabilities in wells, pipelines, or risers:

- 10 ▪ Choking the flow
- Increasing the gas lift rate
- Providing overcapacity to accommodate the gas and liquid slugs

15 Recently, a new alternative method using automatic feedback control was disclosed in the international application WO 02/46577. This method uses measurements of pressure, flow, or temperature as input to an automatic feedback controller for the purpose of stabilizing the flow by continuously
20 manipulating the flow line outlet choke/valve. The measurements are taken upstream of the point where the main part of the slug is formed or is about to occur. Studies using other measurements than the inlet pressure for stabilization are disclosed in E. Storkaas and S. Skogestad:
25 "Cascade Control of unstable systems with application to stabilization of slug flow", presented at IFAC-symposium Adchem'2003. The authors use linear feedback controllers, which continuously manipulate the outlet valve opening in order to stabilize the flow line.

30 However, one significant challenge of operating an inlet pressure feedback controller such as the one in WO 02/46577, is to select the inlet pressure set point given to the controller. Some rules of thumb are given in WO 02/46577
35 without disclosing any specific solution. The set points given to the feedback controller in WO 02/46577 are also

assumed to be manually selected/changed. To realize the importance of the inlet pressure set point, it should first be noted that flow rates into the flow line generally will increase if the flow line inlet pressure decreases. This means that in order to maximize the production from the flow line, its inlet pressure should be kept stable and as low as possible by the feedback controller. However, one cannot use an arbitrary low set point for the inlet pressure. Firstly, it might be impossible for the controller to stabilize the flow line at a too low set point. Secondly, the controllability, that is, the ability to control the inlet pressure using the flow line outlet valve, might become poor. This is due to the fact that by lowering the set point, the valve will typically operate at a valve opening which is, in average, larger. This again implies that the pressure drop across the valve might become very small.

The pressure drop, dP , across the valve gives a measure of the influence changes in the valve opening will have on the fluid movements in the flow line.

In addition, experience has shown that sudden drops in the liquid outflow from the flow line and the associated dP across the outlet valve may occur also after the flow line has been stabilized. The result is poor controllability of the flow line, meaning the outlet valve opening will have little or no effect on the outlet liquid flow. This means that if there is an automatic feedback control law manipulating the outlet valve opening, this will lose control over the flow line and flow instabilities will occur if the flow line is unstable without using feedback control.

As an example, let P_1 denote the flow line inlet pressure, P_2 the upstream valve pressure, P_3 the downstream valve pressure and let the pressure difference across the valve be denoted by $dP = P_2 - P_3$. The valve is assumed to be located at the outlet of the flow line. The inlet flow to the flow line will normally increase if P_1 decreases. If dP decreases at

the same time, indicative of the liquid outflow rate from the flow line is being reduced (assuming a constant valve opening), a mass imbalance in the flow line results. Hence, a liquid blockage in the flow line is probable to occur. In addition, if for example a standard linear PID (Proportional +Integral+Derivative) controller is used for controlling the flow line inlet pressure, the controller might order the valve to reduce its opening (depending on the tuning and choice of inlet pressure set point). The result of this will be an even lower outlet flow. Also, a sudden reduction of the liquid flow out of the pipeline/well may not be sufficiently observable in the inlet pressure before it is too late, that is, before the liquid plug has been established in the flow line. Hence, control laws using only measurements at the flow line inlet for feedback control will probably fail in preventing the drop in the outflow. Therefore, maintaining controllability of the flow line, that is, preventing the liquid outflow from the flow line from approaching zero even for a stabilized flow line, is a significant challenge.

Fig. 5 shows real-site data of a stabilized pipeline. The inlet pressure P1 exhibits relatively small variations (up to time=5 hours). However, at time=3.25 hours, a sudden decrease in the pressure drop across the valve dP occurs. At the same time, P1 is also decreasing. This eventually results in the building-up of a liquid slug and an unstable pipeline flow. This can be observed in the inlet pressure from time=5 hours.

It is however not necessary that a decrease in the inlet pressure takes place in order for a drop in dP to be problematic. This is illustrated by the real-site data shown in Fig. 6. At time=6 hours, a sudden drop in dP results in an unstable pipeline although P1 does not decrease whilst the sudden drop in dP takes place.

For an overview of prior art control methods for stabilization of flow lines, reference is made to the international application WO 02/46577 and its cited references. However, none of the methods in these
5 references, including the method described in WO 02/46577, address the specific problem of preventing that a sudden drop in the liquid outlet flow results in poor flow line controllability, possibly liquid blockage, and eventually an unstable flow line.

10

Summary of the Invention

An objective of the present invention is to provide a method and a system for enhanced control of fluid flow in a flow line. Another objective of the invention is to provide a
15 method and a system adapted to secure a stable flow in the flow line, by preventing the outlet liquid flow from the flow line becoming and staying relatively small, giving rise to poor controllability, mass imbalance (mass inflow differing from mass outflow), and finally a liquid blockage.
20 A further objective of the present invention is to provide a method and a system for ensuring that the controllability of the flow line is maintained.

Said objectives are achieved by a method and a system having
25 the features of claims 1, 2 and 13.

According to a first aspect, the invention is achieved by means of the initially defined method, characterized in that the method includes the steps of:

- 30 - controlling the opening of the valve or choke by means of a control unit,
- measuring or estimating an outlet flow rate or a pressure upstream of the valve or choke, or a pressure difference across the valve or choke, or a fluid density, or a fluid
35 temperature, or any combination thereof, and opening of the valve or choke,

- determining if a sudden drop occurs in any of the measurements or estimates,
- deciding if a liquid blockage in the flow line is present or approaching based on the measurements or estimates,
- 5 and if a liquid blockage is indicated as present or approaching,
- increasing the opening of the valve or choke by an amount determined by the measurements or estimates,
- inhibiting any further manipulation of the valve or choke
- 10 before a non-zero time period has expired, and
- repeating the steps according to the above.

The term sudden drop should be understood to mean a decrease faster than decreases experienced during normal and

15 preferred operating conditions.

The method step of increasing the opening of the valve or choke, should be understood to mean that the increase of the valve opening can be a function of the measured or estimated

20 (current) valve opening.

The method step of inhibiting any further manipulation of the valve or choke, should be understood to mean that this only includes the valve or choke manipulation performed by

25 the method/system itself according to the invention, and it is not required to prevent any valve or choke manipulation performed by other functionalities/systems, such as automatic feedback control of the flow line inlet pressure.

30 According to a second aspect, the invention is achieved by means of the initially defined method including the steps of:

- measuring or estimating an inlet pressure or inlet flow rate at the inlet,
- 35 - controlling the opening of the valve or choke by means of a first control unit comprising an automatic feedback controller as a function of the measurements or estimates of the inlet pressure and an inlet pressure set point, or the

inlet flow rate and an inlet flow rate set point,
characterized in that the method comprises the further steps
of:

- measuring or estimating an outlet fluid flow rate, and/or
- 5 a pressure drop across the valve or choke, and/or a valve or choke opening,
- automatically determining a value for the inlet pressure or the inlet flow rate set point in a second control unit comprising an automatic feedback controller, and
- 10 - providing said inlet pressure or inlet flow rate set point to said first control unit.

According to a preferred embodiment of the invention, the method and system will automatically calculate an inlet

15 pressure- or flow set point, used by an automatic feedback controller for the inlet pressure or inlet flow using the outlet valve or choke, to ensure a constant average pressure drop across the outlet valve/choke and/or a constant average valve/choke opening and/or a constant average fluid flow

20 rate, thereby ensuring that the controllability of the flow line is maintained. Furthermore, the method and system will, based on the current operating conditions, adjust the outlet valve/choke opening if there is an unexpected and significant drop in the liquid outflow. The adjustment is

25 carried out in terms of a quick opening of the outlet valve/choke at isolated points in time to prevent that the liquid outflow becomes, and remains, critically low for some period of time. The valve or choke is hereby being opened, preferably in one step, by a determined amount, which is

30 either predefined or automatically computed, and substantially as rapidly as the valve or choke permits.

The flow line is assumed to carry fluids such as liquid and gas. The invention would typically be applied to flow

35 control of slugging multiphase oil and gas flow lines. The invention does not normally require any new equipment to be installed.

Preferably, the value for the inlet pressure- or the inlet flow rate set point is determined such that the pressure drop across the valve/choke or valve/choke opening or outlet flow rate is kept at a substantially constant value.

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Preferably, the status of the flow in the flow line with respect to stability or instability is obtained via a human-machine interface comprising input means arranged therefore and/or input means from an external system.

10

Preferably, the method comprises the further steps of:

- measuring or estimating a flow rate or the pressure, or the fluid temperature at the inlet of the flow line,
- determining a mass balance of the flow line system, and
- 15 - deciding if said liquid blockage is present or approaching based on said mass balance.

Preferably, the method comprises the further steps of:

- measuring or estimating a trend value of the outlet flow rate or the pressure upstream of the valve or choke, or the pressure difference across the valve or choke, or the fluid density, or the fluid temperature, or any combination thereof, and the opening of the valve or choke in a first window moving with time,
- 20 - measuring or estimating a trend value of the outlet flow rate or the pressure upstream of the valve or choke, or the pressure difference across the valve or choke, or the fluid density, or the fluid temperature, or any combination thereof, and the opening of the valve or choke in a second window moving with time, and if said trend value measured or estimated in the first window falls below a defined percentage of the trend value, either predefined or automatically computed, measured or estimated in the second window,
- 25 - measuring or estimating a trend value of the outlet flow rate or the pressure upstream of the valve or choke, or the pressure difference across the valve or choke, or the fluid density, or the fluid temperature, or any combination thereof, and the opening of the valve or choke in a second window moving with time, and if said trend value measured or estimated in the first window falls below a defined percentage of the trend value, either predefined or automatically computed, measured or estimated in the second window,
- 30 - measuring or estimating a trend value of the outlet flow rate or the pressure upstream of the valve or choke, or the pressure difference across the valve or choke, or the fluid density, or the fluid temperature, or any combination thereof, and the opening of the valve or choke in a second window moving with time, and if said trend value measured or estimated in the first window falls below a defined percentage of the trend value, either predefined or automatically computed, measured or estimated in the second window,
- 35 - deciding whether said liquid blockage is present or approaching.

Preferably, a pressure differential across the valve is measured, and if said pressure differential exceeds a predetermined or automatically computed value, the manipulation of the valve or choke is inhibited.

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Preferably, the valve or choke is controlled only when a predefined time period has expired since last opening step.

The present invention is also achieved by means of the initially defined system, characterized in that the system comprises:

- a control unit controlling the opening of the valve or choke,
 - means for measuring or estimating an outlet flow rate or a pressure upstream of the valve or choke or a pressure difference across the valve or choke, or a fluid density, or a fluid temperature, or any combination thereof, and opening of the valve or choke,
 - means for determining if a sudden drop occurs in any of the measurements or estimates,
 - means for deciding if a liquid blockage in the flow line is present or approaching based on the measurements or estimates,
- and if a liquid blockage is indicated as present or approaching,
- means for increasing the opening of the valve or choke by an amount determined by the measurements or estimates, and
 - means for inhibiting any further manipulation of the valve or choke before a non-zero time period has expired.

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According to a preferred embodiment of the present invention the system comprises:

- means for measuring or estimating an inlet pressure or inlet flow rate at the inlet,
- a first control unit comprising an automatic feedback controller arranged to control the opening of the valve or choke as a function of the measurements or estimates of the

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inlet pressure and an inlet pressure set point, or the inlet flow rate and an inlet flow rate set point, and is characterized in that the system comprises:

- means for measuring or estimating an outlet fluid flow rate from the flow line, and/or a pressure drop across the valve or choke, and/or the valve or choke opening,
- a second control unit comprising an automatic feedback controller arranged to automatically determining a value for the inlet pressure or the inlet flow rate set point to said first control unit, and
- means for providing said inlet pressure- or inlet flow rate set point to said first control unit.

Further advantageous features of the present invention will appear from the following description and the appended claims.

Brief Description of Drawings

For a better understanding of the present invention, a specific description of the invention will now be made by way of examples with reference to the accompanying drawings in which:

Fig. 1 schematically shows a flow line system according to one embodiment of the invention.

Fig. 2 schematically shows another embodiment of the invention including its interactions with an inlet pressure control unit.

Fig. 3 shows a control unit according to the invention in more detail.

Fig. 4 a,b show a block diagram and associated algorithms for the functionality of opening the outlet valve or choke under certain circumstances for the control unit of Fig. 3.

Fig. 5 shows real-site data from a pipeline illustrating the sudden decrease in the pressure drop across the valve and the resulting instability.

5 Fig. 6 shows real-site data from a pipeline illustrating another example of sudden decrease in the pressure drop across the valve and the resulting instability.

Fig. 7 shows an unstable pipeline with two different
10 (constant) valve openings. The figure is the result of OLGA simulations (OLGA: Oil and gas simulator software from Scandpower Petroleum Technology AS).

Fig. 8 shows data from OLGA simulations where the invention
15 is used for stabilizing a pipeline flow without an inlet pressure control unit.

Fig. 9 shows real-site data illustrating the interactions
20 between the inventive control unit and an inlet pressure control unit resulting in a stabilized pipeline.

Detailed Description of the Invention and Preferred Embodiments thereof

The inventive method and system make use of measurement(s)
25 at the flow line outlet, and possibly at the flow line inlet, for adjusting the opening of the upstream valve or choke at the flow line outlet. In a first aspect, the valve or choke opening adjustment can be carried out directly by the inventive control method/system and/or in a second
30 aspect by letting the inventive control method/system automatically provide set points to another control system that controls the inlet pressure or the inlet flow rate of the flow line. Such another control system including an inlet pressure controller is described in the International
35 application WO 02/46577 of which the entire content hereby is incorporated by reference.

Fig. 1 schematically shows a flow line system in which the method and system according to the present invention may be used for automatically controlling the flow. The flow line system includes a flow line 3, a flow line inlet 1 and outlet 2, and a control valve or choke 4 arranged in the flow line 3 at the flow line outlet 2. The flow line system could for example be located between a wellhead platform upstream the flow line inlet 1 and a processing platform downstream the flow line outlet 2. The embodiment as shown in Fig. 1 further employs at least one means for measuring or estimating the liquid outlet flow from the flow line, and a control algorithm implemented in the control unit 5 (also see Figs. 3 and 4). Dependent on the available measurements, the outflow can be measured or estimated by, for example, 1) using measurements from a multiphase flow meter that measures the outlet liquid flow FT2, 2) using the pressure difference $dp = PT2 - PT3$ across the valve or choke as an indication of changes in the outflow, 3) or using dp across the valve or choke in combination with the valve opening and/or densitometer and/or temperature measurements for estimating the outflow. In addition, measurements of the inlet pressure PT1 and/or inlet flow rate FT1 may be used to obtain an indication whether the inflow to the flow line is increasing or decreasing. However, as shown in Fig. 5 and Fig. 6, this is not crucial information. Through the control algorithm implemented in the control unit 5, comprising an automatic feedback controller, the resulting control signal 6 is calculated and sent to the valve or choke 4, and set point signal 7 for the inlet pressure PT1 are calculated and made available to a possible automatic feedback controller for the inlet pressure. According to this embodiment of the present invention, the method/system may be seen as stand-alone.

The present invention can also interact with a prior art automatic feedback controller 8 that controls the inlet pressure by continuously manipulating the same outlet valve or choke 4. This is illustrated in Fig. 2. According to this

preferred embodiment the control unit 5, comprising an automatic feedback controller, automatically provides set points 7 for the inlet pressure PT1 to an automatic feedback controller 8 (inlet pressure controller), which is also
5 manipulating the outlet valve 4 by means of the control signal 6 in addition to control signal 9. Typically signal 6 is added to signal 9 and the sum is sent as an opening signal to the valve or choke 4. The inlet pressure set point 7 given to the automatic feedback controller is hereby
10 automatically adjusted. The set point is changed such that the pressure drop across the manipulated valve or choke 4 is kept at a substantially constant value. This can be regarded as an optimizing feature if the chosen set point for the pressure drop is very low, in the sense that the set point
15 for the inlet pressure will be automatically calculated by the inventive control method/system and will be as low as possible while maintaining control of the flow line. The choice of the value that corresponds to a "very low" pressure drop across the valve is typically based on
20 experience.

One of the basic principles behind the inventive method/system is to detect if the outlet flow rate or the pressure PT2 upstream of the valve or choke, or the pressure
25 difference dP across the valve or choke, or the fluid density at the flow line outlet, or the fluid temperature upstream the valve or choke, or any combination thereof, decreases significantly by a sudden drop, and if so, to prevent a sustained drop by abruptly open the outlet valve
30 or choke by a defined amount, which may be predefined or automatically computed, and as rapidly as the valve or choke permits. Hence, the method will first detect if the outlet flow is decreasing more than normal or is ceasing. What is normal will be dependent on the specific case and based on
35 experience. After the control method/system detects a sudden drop in any of the above-mentioned parameters, it determines if it is necessary to quickly open the valve in order to counteract this sudden drop. If a quick opening of the valve

is necessary, the method/system will open the valve in an abrupt manner trying to re-establish the outlet flow. The amount the valve is opened depends on the current operating condition (see below). The inventive control method/system will only adjust the valve opening, in terms of an opening, at isolated points in time. This is in contrast to, for example, an automatic feedback controller for the inlet pressure, which will continuously manipulate the valve opening. The timing of the opening of the valve and how much the valve is opened are two critical factors in deciding the success of the method.

There are two situations in which the control method/system will not open the valve regardless of a significant drop in the outlet flow. The first situation is if the pressure drop across the valve is large. This is to avoid harming the downstream equipment. The second situation is if the method/system just has opened the valve. If the method/system just has taken action in terms of a quick opening, it must wait a non-zero time period before it is allowed to open the valve again, that is, inhibiting any further manipulation of the valve or choke before a non-zero time period has expired. The non-zero time period could be predefined or automatically computed. The time period depends on the specific operational conditions of the flow line system to be controlled. The inhibition is to be understood to be related only to the inventive method/system meaning that valve or choke manipulation(s) performed by other functionalities/ systems, such as automatic feedback control of the flow line inlet pressure, is not inhibited.

Example of preferred algorithms

Referring to the control system shown in Fig. 3, the input signals to the control unit 5 are measurements or estimates of the flow line inlet pressure PT1, current valve opening value u , upstream valve pressure PT2, downstream valve pressure PT3, set point for $dP=PT2-PT3$, and the status of the flow line, that is, whether the flow line is stable or

unstable (slugging). The output signals from the control unit are valve opening value(s) and set point(s) for the inlet pressure PT1. It is indicated in Fig. 3 that PT1 can be replaced by an inlet flow rate measurement or estimate FT1, whilst PT2 and PT3 can be replaced by an outlet flow rate measurement FT2 or estimate.

The inventive method/system calculates the pressure drop across the valve dP and subtracts this from the set point for dP which is, for example, provided by an operator. The result is, for example, sent to a 1st order low-pass filter which may be described as:

$$FilteredValue_k = \exp\left(-\frac{T_sample}{T_filter}\right) \cdot FilteredValue_{k-1} + \left\{1 - \exp\left(-\frac{T_sample}{T_filter}\right)\right\} \cdot Value_k$$

where T_sample is the sampling time and T_filter is the filter time constant. The filtered value is, for example, sent to a PID controller (controller with Proportional, Integral and Derivative action), as shown in Fig. 3 by way of a preferred example, whose output will be the set point for the inlet pressure. The set point for the inlet pressure is preferably continuously changed to maintain the pressure drop across the valve or choke at a substantially constant value. However, this set point has no meaning if the flow line is unstable. Hence, the set point will not be used if the flow line is slugging. This means that information about the stability of the flow line ("Status Flow Line", see Fig. 3) must be provided, for example, by an operator via a human-machine interface comprising input means arranged for providing the status of the flow in the flow line with respect to stability or instability and/or input means for obtaining such information from an external system.

At the same time, the inventive control method/system monitors the pressure drop across the valve and takes action if the pressure drop suddenly decreases abnormally fast (cf. Fig. 5 and Fig. 6). Fig. 4 shows a detailed block-diagram of how this can be carried out.

The different blocks of the block-diagram of Fig. 4 will now be described.

1) Filtering/Derivation

5 In this pre-processing block the raw values of the flow line inlet pressure, P_1 , and the pressure drop across the valve ($dP=P_2-P_3$) are processed by a 1st order low-pass filter, and, in two cases, by a differentiation with respect to time combined with a second 1st order filter (to
10 limit the derivative action at high frequencies). These pre-processed values of P_1 and dP are then used as input to several succeeding blocks.

2) Observation of B_a (Blocking avoidance) influence on the pipeline/well

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This block contains two sub-blocks: a Steady State Detection block and a System Stabilized Detection block. Both of these sub-blocks process the two filtered time derivatives from the Filtering/Derivation block. In the
20 Steady State Detection block it is detected whether the flow line is in steady state or not. By the term steady state it is meant that the flow line pressures are stable. This is carried out by checking if the absolute values of the time derivatives are small enough over a long enough
25 period of time ($BaT7_W$ seconds). In the System Stabilized Detection block, it is checked if the values of the time derivatives are contained in a given band for a certain period of time ($BaT6_W$ seconds). By the term system stabilized it is meant that the flow out of the
30 pipeline/well is "picking up", i.e. the flow out of the pipeline/well has been "saved" from ceasing. Typically this is characterized by that the time derivative of dP is large enough while the time derivative of P_1 (Fig. 4: PT_1) is small enough for a certain period of time ($BaT6_W$ seconds).

3) Filling of four windows used to check if a liquid blockage is about to occur, and if so, deciding if the valve should be opened or not

As illustrated in Fig. 4, by way of example, there are four
5 windows/queues moving with time: BufferWindow, LargeWindow,
SmallWindow_DP, and SmallWindow_CoOut. These windows keep
track of the evolution or trend of dP, a filtered version
of the dP, and the valve movement, contributing to the
functionality according to this embodiment of the present
10 invention. The windows/queues are preferably of the type
First In First Out (FIFO). The BufferWindow before the so-
called LargeWindow (second window) is used in order to make
the values contained in the LargeWindow represent the
"normal" range of values for a filtered version of dP in a
15 steady state situation for the flow line. The LargeWindow
is used in connection with detecting if a liquid blockage
is about to occur after the flow line has reached a steady
state. The so-called SmallWindow_DP (first window) contains
the evolution of a non-filtered version of dP. Generally it
20 might be required to filter the dP values contained in the
SmallWindow_DP also. The SmallWindow_DP is used in
connection with detecting if a liquid blockage is about to
occur during the initial phase of stabilization after a
slug has been received.

25 It should be noted that the sizes of the "small" and
"large" window ($BaT1_W$ and $BaT3_W$ seconds) are determined
by the user/operator, and, in general, the "small" window
may be larger than the "large" window ($BaT1_W > BaT3_W$). If
30 there is another controller that for example controls the
inlet pressure, the SmallWindow_CoOut is used in order to
keep track of how this other controller is contributing to
the total output given to the valve. If, for example, the
inlet pressure controller is opening the valve sufficiently
35 by itself such that a liquid blockage is expected to be
avoided, the inventive control method/system will have zero
contribution to the total output given to the valve. In the
case when the system contributed with a positive "jump" in

the total output, it could possibly lead to a subsequent destabilization of the flow line, because the flow line inlet pressure, and hence the potential energy in the flow line, could be drawn too low to sustain the possibility of carrying liquid up the flow line, such as a riser/well. To make sure that the output sent to the valve is queued in SmallWindow_CoOut, this window must be updated when the computation of the total output given to the valve is finished (including upper/lower bounding of the final valve signal). This is carried out in the Controller Output Computation block.

4) *Enabling of "small" window action*

By enabling of "small" window action it is meant that the inventive method/system may contribute by a positive "jump" to the total output given to the valve if it is required in order to avoid a liquid blockage in the flow line, and if in addition it is allowed (see below). Whether it is required or not is based on the evolution of dP and the evolution of total output from the inlet pressure controller contained in SmallWindow_DP and SmallWindow_CoOut, respectively. For "small" window action to be enabled it is required that the dP across the valve is below a certain limit ($BaLim1_DP$), the reason being that if the valve suddenly is opened with a high dP across it, it may cause serious downstream problems that are more important to avoid than it is to stabilize the flow line. Additionally, the flow line should not already be considered as stabilized.

This enabling block could just as well have been integrated with the block *Checking if "small" window action is allowed*, and the resulting integration named *Enabling of "small" window action* or *Checking if "small" window action is allowed*.

5) *Enabling of "large" window action*

The meaning of enabling is the same in this case as for enabling of "small" window action. For enabling of "large" window action it is required that it has been detected that the flow line is in steady state and that sufficient time has elapsed so that the LargeWindow is filled. (The BufferWindow is, in fact, necessarily filled if the LargeWindow is filled.)

This enabling block could just as well have been integrated with the block *Checking if "large" window action is allowed*, and the resulting integration named *Enabling of "large" window action* or *Checking if "large" window action is allowed*.

6) *Resetting*

If the pressure drop dP across the valve exceeds a certain limit ($BaLim1_DP$), the enabling of "small"- and "large" window action is reset, and so is the detection of steady state as well as the detection of system stabilized. This means that if dP exceeds this limit, the inventive control method/system will not contribute to the total output given to the valve. Thus, there will be a zero contribution from the inventive control method/system.

7) *Checking if "small" window action is allowed*

"Small" window action is allowed only if it is enabled, the inventive control method/system itself is enabled, all queue operations during initialization (i.e. 1st cycle run) were all right, and no waiting after last "small" window action is going on.

Reference is also made to the above description of *Enabling of "small" window action*.

8) Checking if "large" window action is allowed

"Large" window action is allowed only if it is enabled, the inventive control method/system itself is enabled, all queue operations during initialization (i.e. the 1st cycle run) were all right, and no waiting after the last "large" window action is going on.

9) Checking if "large" window action is required

Action in the sense of creating a positive "jump" in the valve/choke opening in order to avoid liquid blockage in the flow line is required if the current filtered dP across the valve is less than a certain percentage of the lowest filtered dP contained in the "large" window. This lowest dP represents a "normally" low dP in steady state.

This should be understood to mean that if the current flow estimate is very low compared to what is normal in steady state, the flow probably is ceasing and that the valve/choke should be "jumped" open to get the flow going again.

10) Checking if "small" window action is required

Action in the sense of creating a positive "jump" in the valve/choke opening in order to avoid liquid blockage in the flow line is required if the increase in output to the valve/choke across the SmallWindow_CoOut, assuming zero contribution from the inventive control method/system, at current sample is too small, and the output to the valve/choke, with zero contribution from the method/system, is not too high already, and the drop in valve dP during the time period representing the "small" window is large enough, and the current sample of the valve dP is smaller than the one at the previous sample.

This should be understood to mean that if the flow out of the flow line has been dropping rapidly for a while after having received a slug, and is currently dropping rapidly

as well, the valve/choke should be rapidly opened by the control method/system to get the flow going again, to avoid another slug forming, provided that the choke/valve is not already opening fast enough and the choke/valve is not
5 already too open (so as to reduce the risk of causing problems downstream).

11) Computing "jump" in Out when "small" or "large" window action is required

10 If it is found that "small" or "large" window action is required, it is essentially attempted to add a positive value from the control method/system to *BaOpening* which is given to the choke/valve. If, however, the opening with zero contribution from the method/system exceeds
15 *BaLim1_u_KP*, but is below *BaLim2_u_KP*, *BaOpening* is scaled by *BaKP_scaling*. If the opening with zero contribution from the method/system exceeds *BaLim2_u_KP* the contribution from the method/system will be zero.

20 If the resulting valve opening exceeds *BaLim2_u_KP* after adding the contribution from the method/system, the resulting contribution from the method/system will be a percentage, given by *BaKP_scaling2*, of the difference between *BaLim2_u_KP* and the choke/valve opening with zero
25 contribution from the method/system.

12) Wait after "large" window action

After a "large" window action has taken place, a certain period of time (*BaT5_W* seconds) should pass before the next
30 "large" window action is allowed.

13) Wait after "small" window action

After a "small" window action has taken place, a certain period of time (*BaT2_W* seconds) should pass before the next
35 "small" window action is allowed.

14) Making sure $BaOut \geq 0$

The action from the control method/system in terms of an adjustment of the valve opening should be positive.

5 15) Controller Output Computation

The choke/valve output signal is ready to be sent to the valve.

The currently described control method and system have been
10 tested by using OLGA simulations of a pipeline. The pipeline is slugging (unstable) using constant valve openings of 20% and 30%. This is shown in Fig. 7. The inventive method/system was tested without using an automatic feedback control for the inlet pressure and the result is shown in
15 Fig. 8. The system was turned on at time=4 hours. It can be seen that it takes action at time=5.4 hours by increasing the valve opening in a nonlinear manner when the pressure drop across the valve starts to suddenly drop. The result is that the flow line is stabilized and the decrease in the
20 pressure drop across the valve stops.

Fig. 9 shows real operational data from control of a slugging pipeline by using the inventive method/system together with an inlet pressure controller. "Out" in the
25 figure is the commanded valve opening. It can be seen that the method/system opens the valve at four isolated points in time when it has detected sudden drops in $dP (=P_2-P_3)$. Three times due to "small" window actions and one time due to "large" window action as indicated by respective arrows in
30 Fig. 9. In this case, the size of the "small" window is about 7.5 minutes, whereas the "large" window is about 25 minutes. Although the "small"- and "large" window actions are inhibited for a non-zero period of time after such actions have taken place, it can be observed that the
35 accompanying automatic feedback control of the inlet pressure, P_1 , is continuously manipulating the choke. Also, "small"- and "large" window actions are inhibited whenever

dP is above BALim1_DP to avoid possible large disturbances to downstream equipment. Events like "System Stabilized Detected" and "Steady State Detected" which influence the way the algorithm behaves is also indicated. The result is
5 that the pipeline is stabilized.

It should further be noted that the inventive control method/system comprises a highly nonlinear component as opposed to a standard linear PID controller. Another
10 difference between conventional automatic feedback controllers and the inventive method/system is that the inventive method/system typically increases the valve opening abruptly at isolated points in time as opposed to a continuous (in time) manipulation of the valve in both
15 directions.

The method according to the present invention may be implemented as software, hardware, or a combination thereof. A computer program product implementing the method or a part
20 thereof comprises a software or a computer program run on a general purpose or specially adapted computer, processor or microprocessor. The software includes computer program code elements or software code portions that make the computer perform the method using at least one of the steps according
25 to the inventive method.

The program may be stored in whole or part, on, or in, one or more suitable computer readable media or data storage means such as a magnetic disk, CD-ROM or DVD disk, hard
30 disk, magneto-optical memory storage means, in RAM or volatile memory, in ROM or flash memory, as firmware, or on a data server.

It will be understood by those skilled in the art that
35 various modifications and changes may be made to the present invention without departure from the scope thereof, which is defined by the appended claims.

CLAIMS

1. A method for automatically controlling a flow in a flow line system, said flow line system including a flow line (3), a flow line inlet (1) and outlet (2), and a control valve or choke (4) located in the flow line (3) at the outlet (2),
- 5 characterized in that said method includes the steps of:
- controlling the opening of the valve or choke by means of a control unit (5),
 - 10 - measuring or estimating an outlet flow rate (FT2) or a pressure (PT2) upstream of the valve or choke, or a pressure difference (dP) across the valve or choke, or a fluid density, or a fluid temperature, or any combination thereof, and opening of the valve or choke,
 - 15 - determining if a sudden drop occurs in any of the measurements or estimates,
 - deciding if a liquid blockage in the flow line is present or approaching based on the measurements or estimates, and if a liquid blockage is indicated as present or
 - 20 approaching,
 - increasing the opening of the valve or choke (4) by an amount determined by the measurements or estimates,
 - inhibiting any further manipulation of the valve or choke (4) before a non-zero time period has expired, and
 - 25 - repeating the steps according to the above.
2. A method for automatically controlling a flow in a flow line system, said flow line system including a flow line (3), a flow line inlet (1) and outlet (2), and a control
- 30 valve or choke (4) located in the flow line (3) at the outlet (2), said method including the steps of:
- measuring or estimating an inlet pressure (PT1) or inlet flow rate (FT1) at the inlet (1),
 - controlling the opening of the valve or choke (4) by means
 - 35 of a first control unit (8) comprising an automatic feedback controller (8) as a function of said measurements or

estimates of the inlet pressure (PT1) and an inlet pressure set point, or the inlet flow rate (FT1) and an inlet flow rate set point,

characterized in that said method comprises the

5 further steps of:

- measuring or estimating an outlet fluid flow rate (FT2), and/or a pressure drop (dP) across the valve or choke, and/or a valve or choke opening,

- automatically determining a value for the inlet pressure or the inlet flow rate set point in a second control unit (5) comprising an automatic feedback controller, and

- providing said inlet pressure- or inlet flow rate set point to said first control unit (8).

15 3. A method according to claim 2, characterized by determining the value for the inlet pressure- or the inlet flow rate set point such that the pressure drop across the valve/choke or valve/choke opening or outlet flow rate is kept at a substantially constant
20 value.

4. A method according to claim 2, characterized by obtaining the status of the flow in the flow line with respect to stability or instability via a human-machine
25 interface comprising input means arranged therefore and/or input means from an external system.

5. A method according to claims 2-4, characterized in that said method comprises the
30 steps of:

- measuring or estimating an outlet flow rate (FT2) or a pressure (PT2) upstream of the valve or choke, or a pressure difference (dP) across the valve or choke, or a fluid density, or a fluid temperature, or any combination thereof,
35 and opening of the valve or choke,
- determining if a sudden drop occurs in any of the measurements or estimates,

- deciding if a liquid blockage in the flow line is present or approaching based on the measurements or estimates, and if a liquid blockage is indicated as present or approaching,

- 5 - increasing the opening of the valve or choke (4) by an amount determined by the measurements or estimates,
- inhibiting any further manipulation of the valve or choke (4) before a non-zero time period has expired, and
- repeating the steps according to the above.

10

6. A method according to claim 1, characterized in that the method comprises the further steps of:

- measuring or estimating a flow rate (FT1) or the pressure
- 15 (PT1), or the fluid temperature at the inlet (1) of the flow line (3),
- determining a mass balance of the flow line system, and
- deciding if said liquid blockage is present or approaching based on said mass balance.

20

7. A method according to claim 1, characterized in that the method comprises the further steps of:

- measuring or estimating a trend value of the outlet flow
- 25 rate (FT2) or the pressure (PT2) upstream of the valve or choke, or the pressure difference (dP) across the valve or choke, or the fluid density, or the fluid temperature, or any combination thereof, and the opening of the valve or choke in a first window moving with time,
- 30 - measuring or estimating a trend value of the outlet flow rate (FT) or the pressure (PT2) upstream of the valve or choke, or the pressure difference (dP) across the valve or choke, or the fluid density, or the fluid temperature, or any combination thereof, and the opening of the valve or
- 35 choke in a second window moving with time, and if said trend value measured or estimated in the first window falls below a defined percentage of the trend value measured or estimated in the second window,

- deciding whether said liquid blockage is present or approaching.

8. A method according to claim 1,
5 characterized by
- measuring a pressure differential across the valve (4),
and
if said pressure differential exceeds a predetermined or
automatically computed value,
10 - inhibiting manipulation of the valve or choke (4).

9. A method according to claim 1,
characterized by measuring said outlet flow rate with
a multiphase flow meter.

15 10. A method according to claim 1,
characterized by estimating said outlet flow rate
from measurements of a pressure differential across the
valve (4).

20 11. A method according to claim 1,
characterized by estimating said outlet flow rate
from measurements of a pressure differential across the
valve (4) and measurements of valve or choke opening and/or
25 density of the fluid flowing in the flow line.

12. A method according to claim 1,
characterized by controlling the valve (4) only when
a predefined time period has expired since last opening
30 step.

13. A system for automatically controlling a flow in a flow
line system, said flow line system comprises a flow line (3)
inlet (1) and outlet (2), and a control valve or choke (4)
35 located in the flow line (3) at the outlet (2),
characterized in that the system comprises:
- a control unit (5) controlling the opening of the valve or
choke,

- means for measuring or estimating an outlet flow rate (FT2) or a pressure (PT2) upstream of the valve or choke or a pressure difference (dP) across the valve or choke, or a fluid density, or a fluid temperature, or any combination thereof, and opening of the valve or choke,
 - means for determining if a sudden drop occurs in any of the measurements or estimates,
 - means for deciding if a liquid blockage in the flow line is present or approaching based on the measurements or estimates,
- and if a liquid blockage is indicated as present or approaching,
- means for increasing the opening of the valve or choke (4) by an amount determined by the measurements or estimates,
- and
- means for inhibiting any further manipulation of the valve or choke (4) before a non-zero time period has expired.

14. A system according to claim 13, wherein said flow line system includes a flow line (3) inlet (1) and outlet (2), a control valve or choke (4) located in the flow line (3) at the outlet (2),
- means for measuring or estimating an inlet pressure (PT1) or inlet flow rate (FT1) at the inlet (1),
- a first control unit (8) comprising an automatic feedback controller arranged to control the opening of the valve or choke (4) as a function of the measurements or estimates of the inlet pressure (PT1) and an inlet pressure set point, or the inlet flow rate (FT1) and an inlet flow rate set point, characterized in that the system comprises:
- means for measuring or estimating an outlet fluid flow rate (FT2) from the flow line (3), and/or a pressure drop (dP) across the valve or choke (4), and/or the valve or choke opening,
 - a second control unit (5) comprising an automatic feedback controller arranged to automatically determining a value for the inlet pressure or the inlet flow rate set point to said first control unit (8), and

- means for providing said inlet pressure- or inlet flow rate set point to said first control unit (8).

15. A system according to claim 13, characterized
5 in that the system comprises means to enable the control unit (5) to control the valve (4) only when a predefined time period has expired since last opening step.

16. A system according to claim 14, characterized
10 by a human-machine interface comprising input means arranged for obtaining the status of the flow in the flow line with respect to stability or instability and/or input means from an external system.

15 17. A computer program product comprising computer code means and/or software code portions for making a processor perform any of the steps according to claims 1-12.

18. A computer program product according to claim 17
20 supplied via a network, such as Internet.

19. A computer readable medium containing a computer program product according to claim 17 or 18.

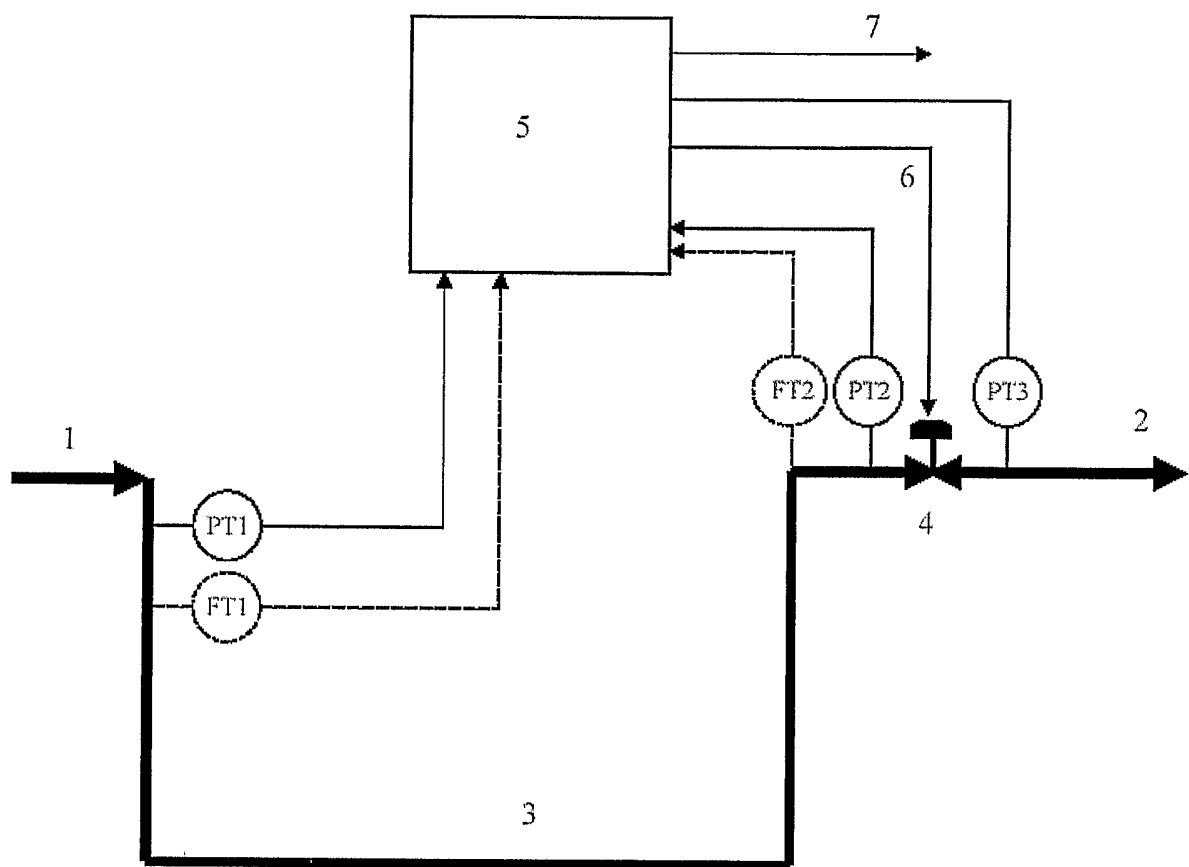


Fig. 1

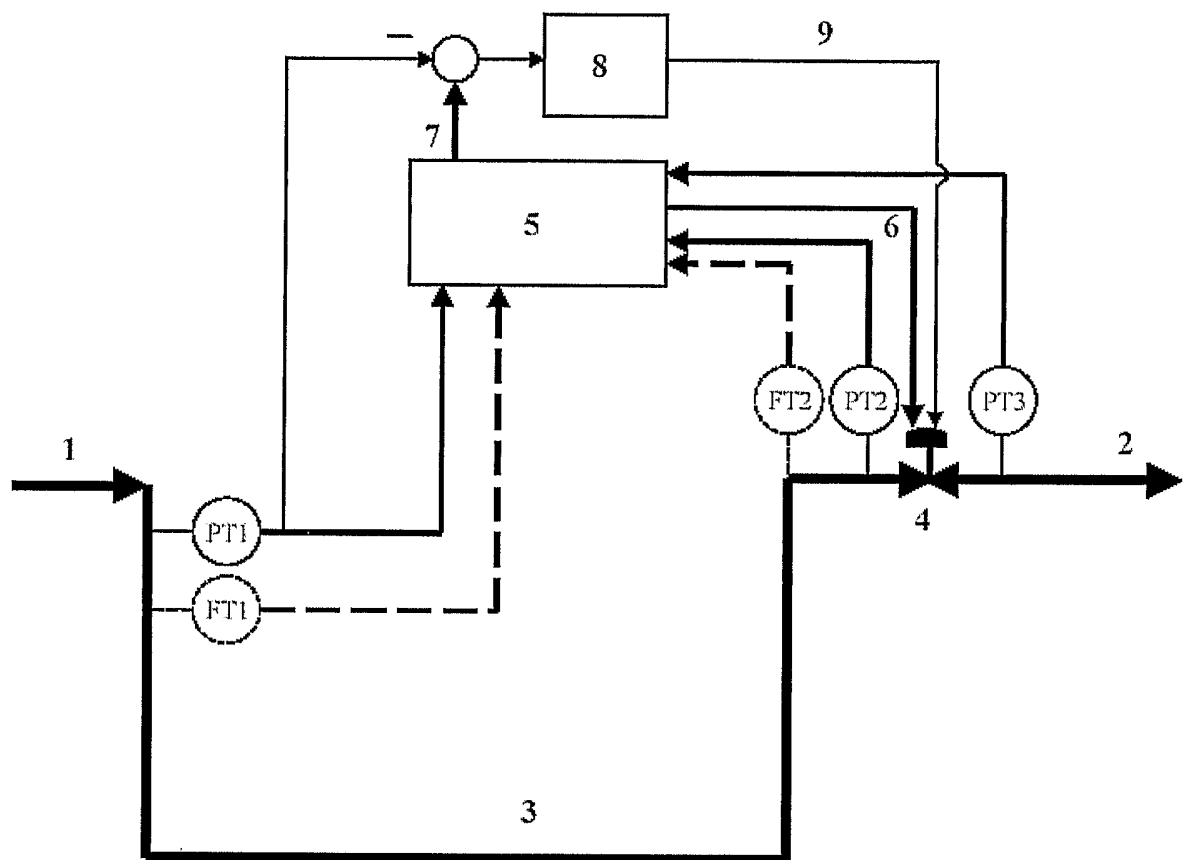


Fig. 2

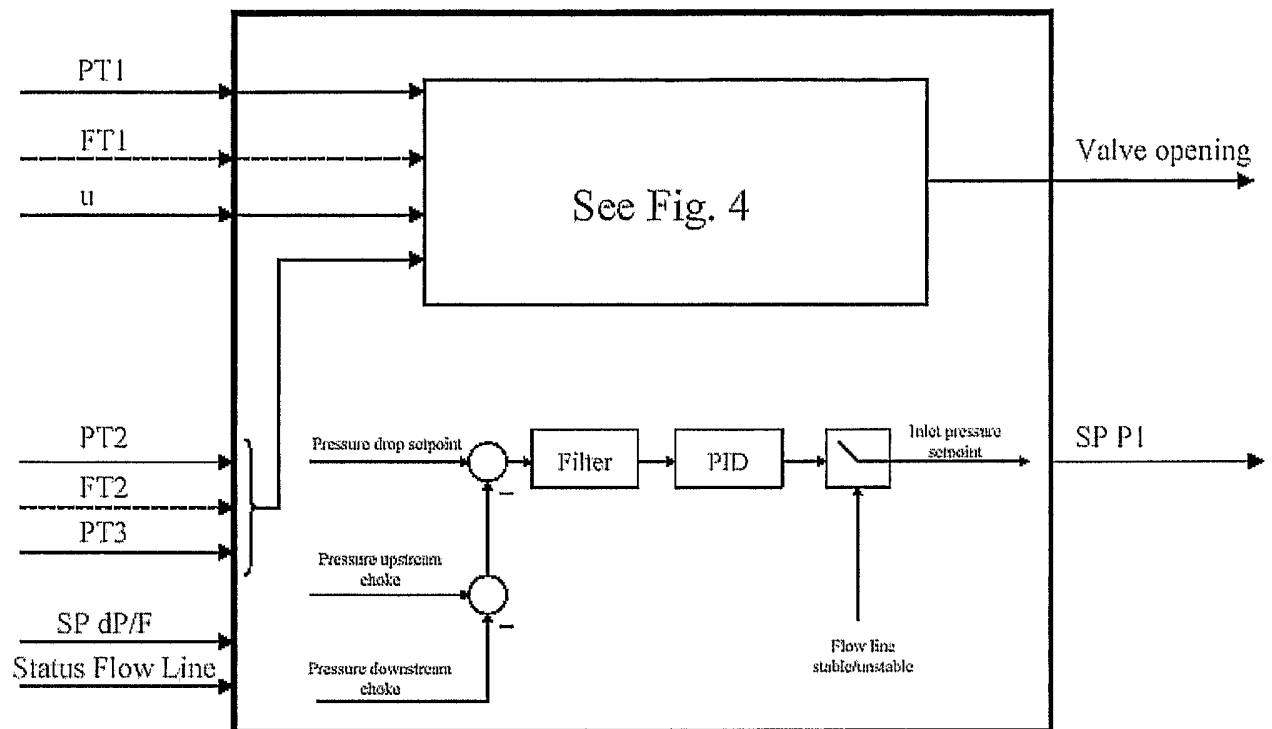


Fig. 3

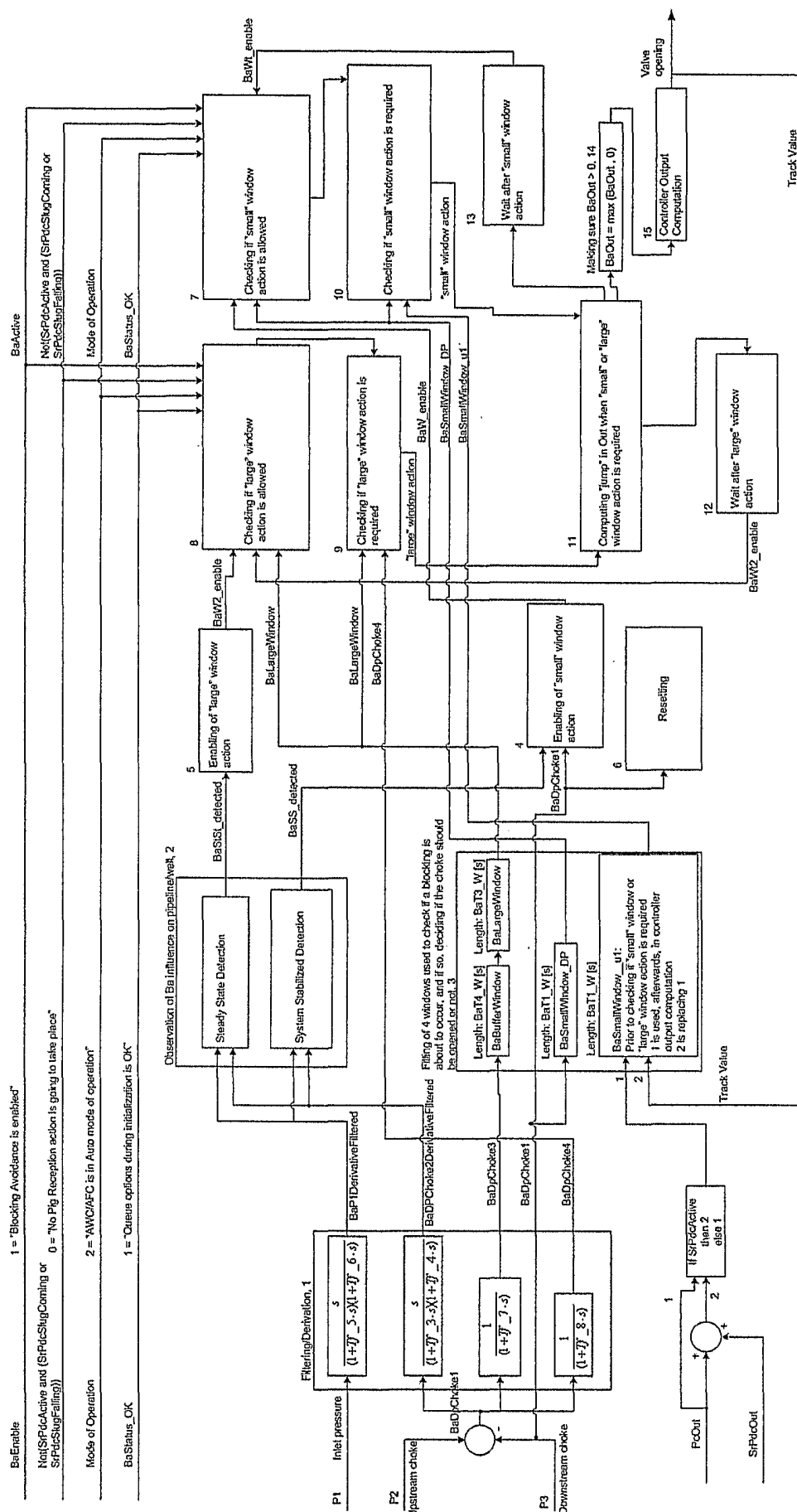


Fig. 4a

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2) Observation of Ba influence on
pipeline/well
- Steady State Detection:
If |BaDpChoke2DerivativeFiltered|
< BaLim1_dDP_f_dt &
|BaP1DerivativeFiltered| <
BaLim1_dP1_f_dt & not
(BaStSt_detected = 1)
for BaT7_W seconds then
BaStSt_detected = 1
- System Stabilized Detection:
If BaDpChoke2DerivativeFiltered <
BaLim2_dDP_f_dt_pos
& BaDpChoke2DerivativeFiltered >
BaLim2_dDP_f_dt_neg
& BaP1DerivativeFiltered <
BaLim1_dP1_f_dt_pos
& BaP1DerivativeFiltered >
BaLim1_dP1_f_dt_neg
& not (BaSS_detected = 1)
for BaT6_W seconds then
BaSS_detected = 1

4) Enabling of "small" window
action:
If BaDpChoke1 < BaLim1_DP then
    If BaSS_Detected = 1 then
        BaW_enable = 0
    else
        BaW_enable = 1
    end
end

5) Enabling of "large" window
action:
If BaStSt_detected and both
BaBufferWindow
and BaLargeWindow are filled then
BaW2_enable=1

7) Checking if "small" window
action is allowed:
If BaSmallWindow is filled
& BaW_enable = 1
& not ( BaWt_enable = 1)
then
"Small" window action is allowed

8) Checking if "large" window
action is allowed:
If BaLargeWindow is filled
& BaW2_enable = 1
& not ( BaWt2_enable = 1)
then
"Large" window action is allowed

9) Checking if "large" window
action is required:
    If minimum (BaLargeWindow) -
BaDpChoke4 >

```

```

BaLim2_DP*minimum(BaLarge_Window)
then
"Large" window action is required

10) Checking if "small" window action
is required:
If (Increase in out across
BaSmallWindow_u1) / BaT1_W)
    < BaLim1_du_dt_SW
    & (Out with BaOut = 0) < BaLim1_u
    & (drop in DP across BaSmallWindow_DP
    / BaT1_W)
        > BaLim1_dDP_dt_SW
    & current DP_choke <= previous
    DP_choke then
"small" window action is required

11) Computing "jump" in Out when
"small" or "large" window action is
required:
If (Out with BaOut = 0) < BaLim1_u_KP
then
    If ((Out with BaOut = 0) +
BaOpening) >= BaLim2_u_KP then
        BaOut = (lim2_u_KP_BA - Out
with BaOut = 0))
        * BaKP_scaling2
    else
        BaOut_temp = BaOpening
    end
elseif (Out with BaOut = 0) <
BaLim2_u_KP then
    If (Out with BaOut = 0) +
BaOpening * BaKP_scaling
        >= BaLim2_u_KP then
        BaOut = (BaLim2_u_KP -
BaTmp2) * BaKP_scaling2
    else
        BaOut = BaKP_scaling *
BaOpening
    end
else
    BaOut = 0
end

12) Wait after "large" window action:
If elapsed waiting time < BaT5_W then
    BaWt2_enable = 1
else
    BaWt2_enable = 0
end

13) Wait after "small" window action
If elapsed waiting time < BaT2_W then
    BaWt_enable = 1
else
    BaWt_enable = 0
end

```

Fig. 4b

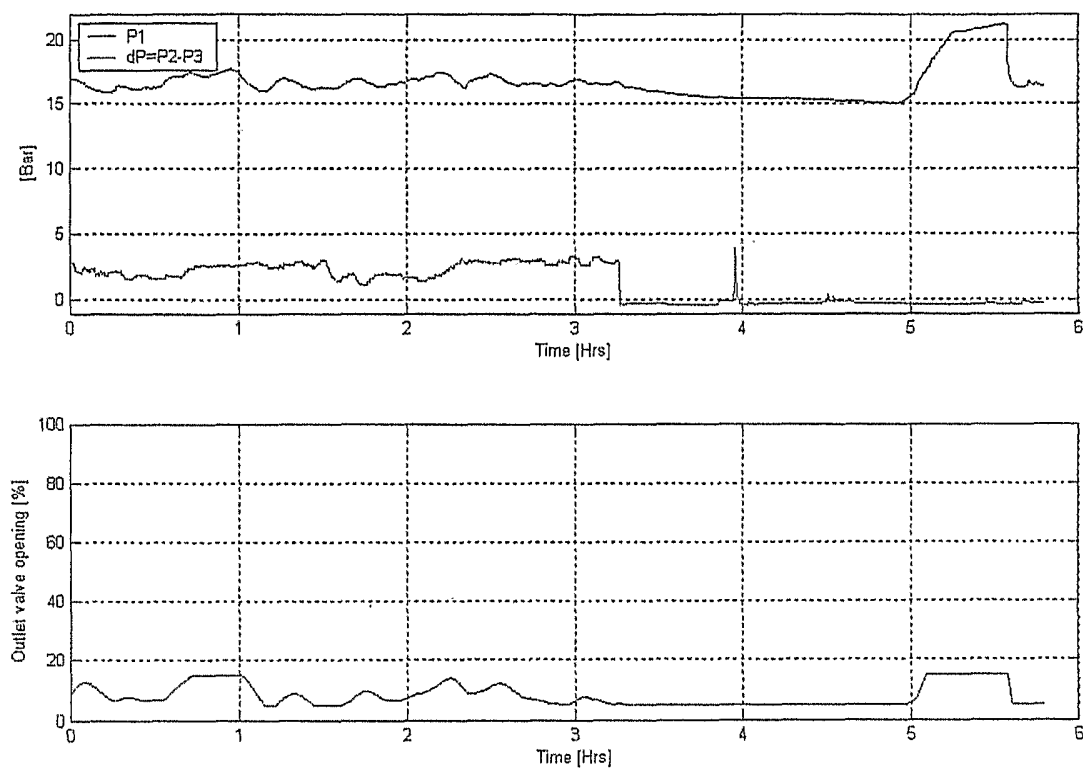


Fig. 5

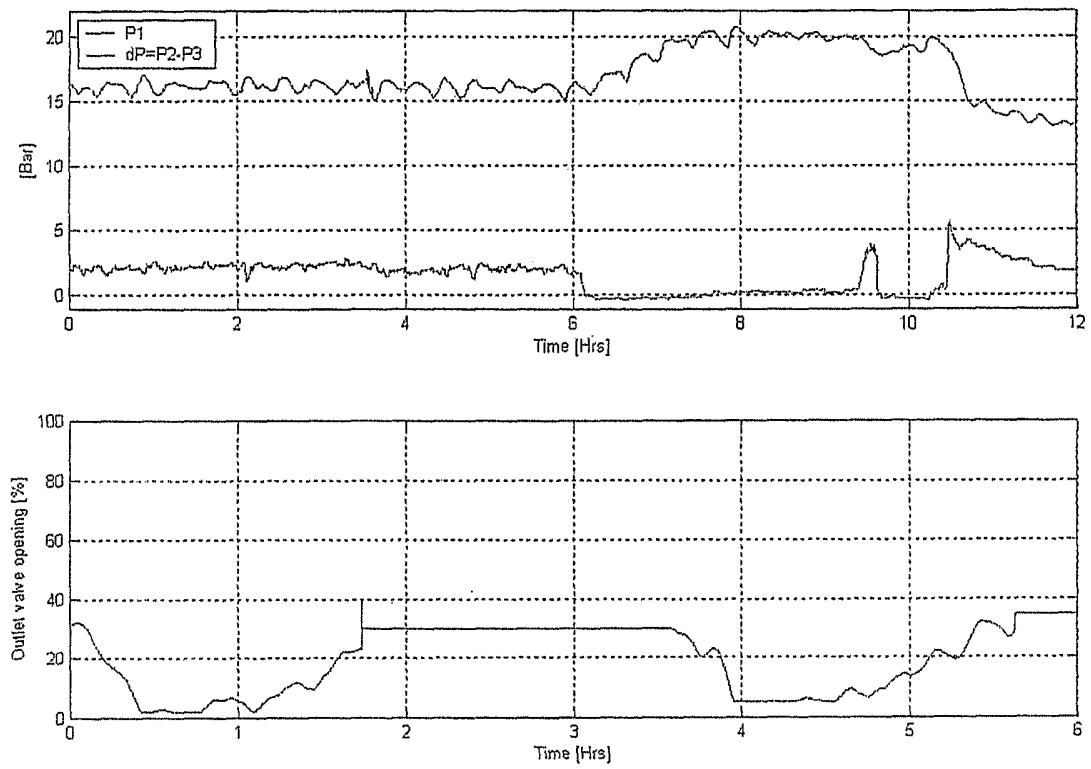


Fig. 6

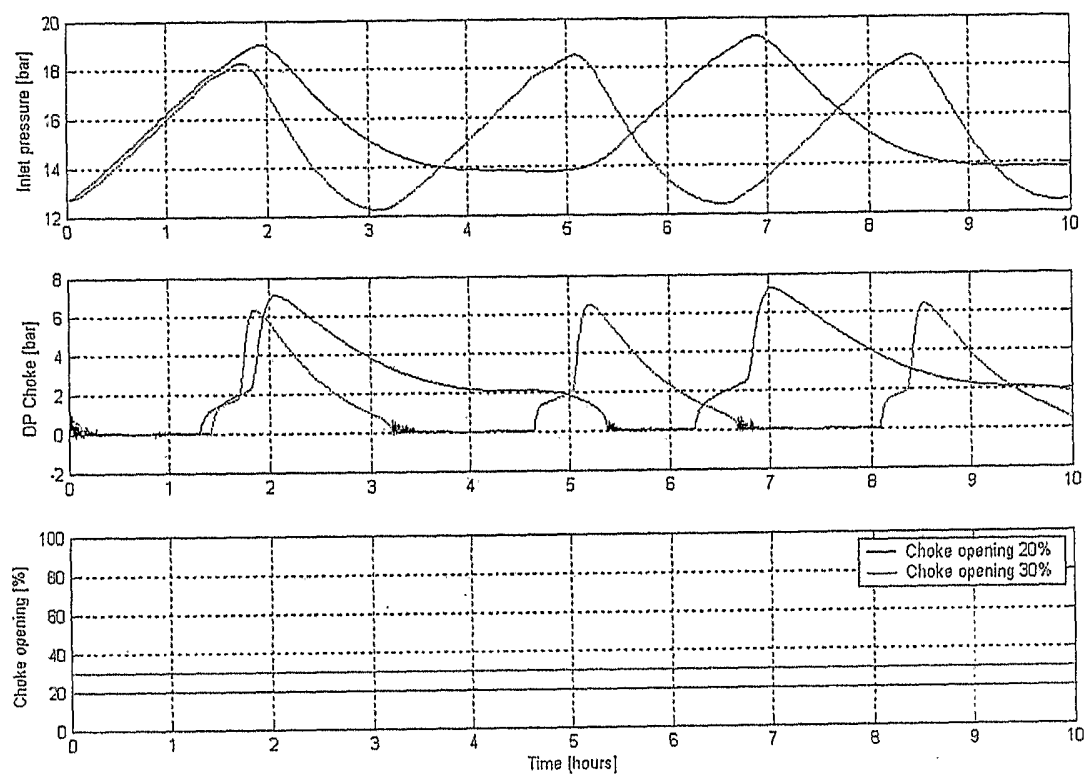


Fig. 7

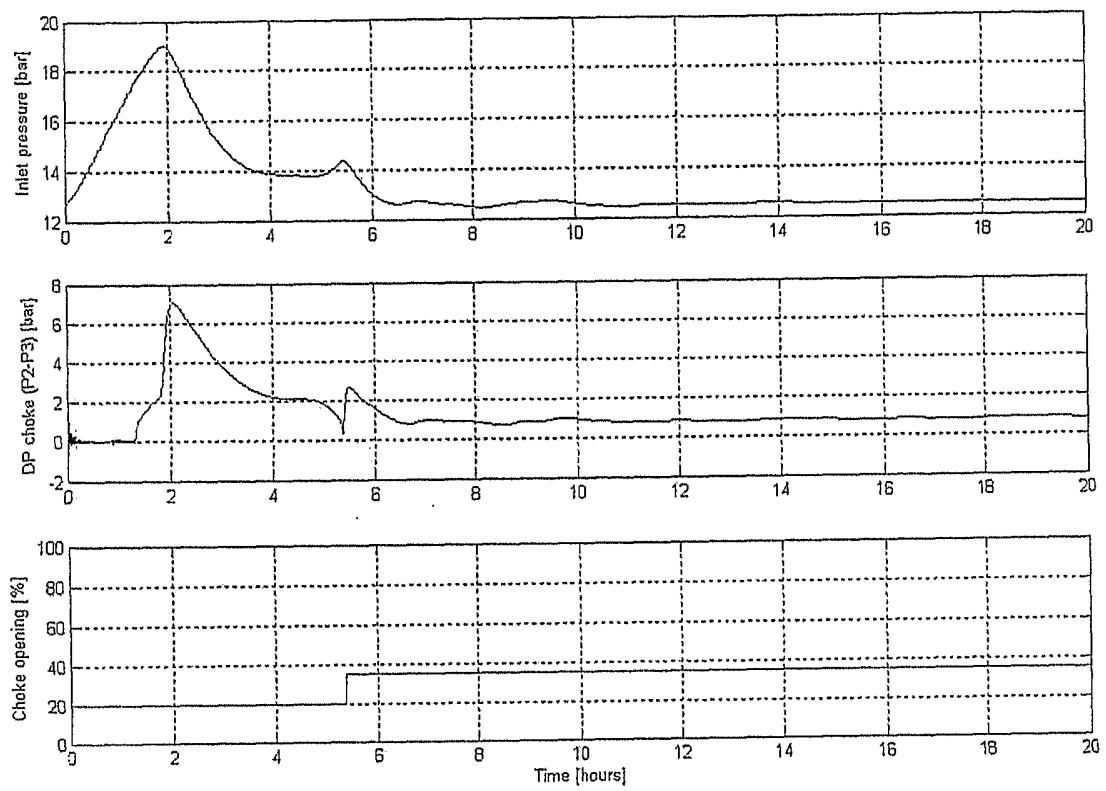


Fig. 8

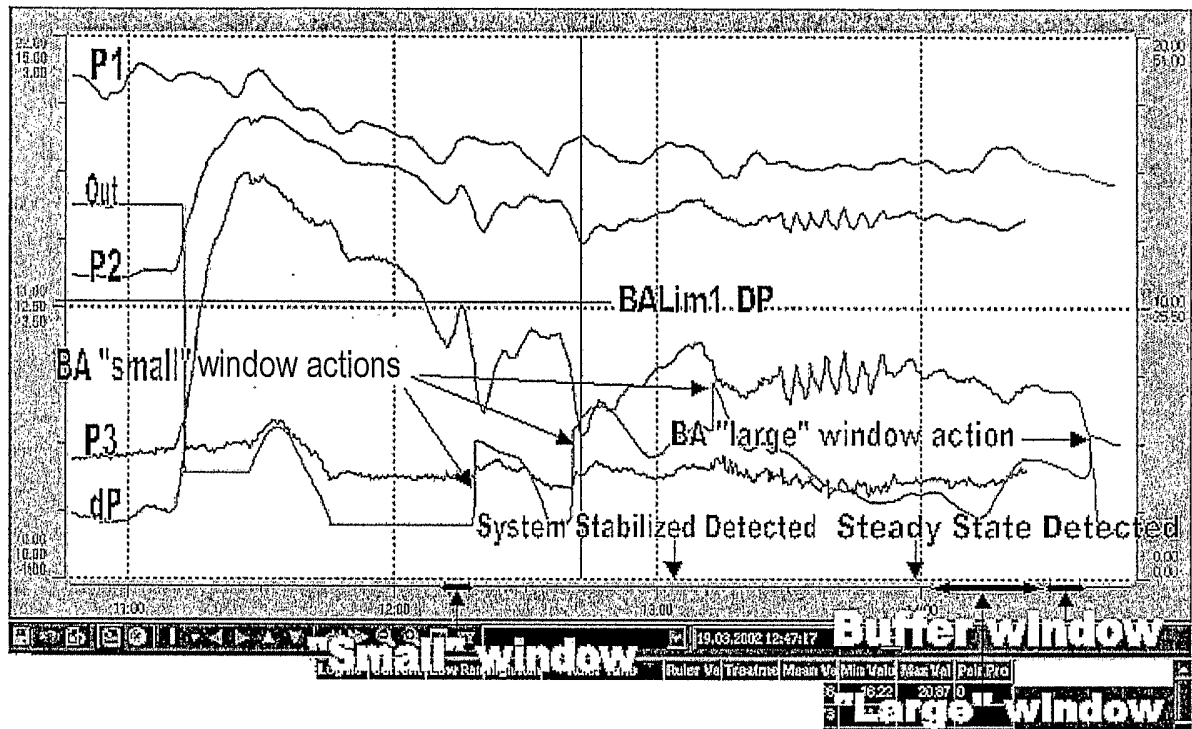


Fig. 9