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**(54) Title**: METHOD AND APPARATUS FOR SELF VERIFICATION OF PRESSURE BASED MASS FLOW CONTROLLERS

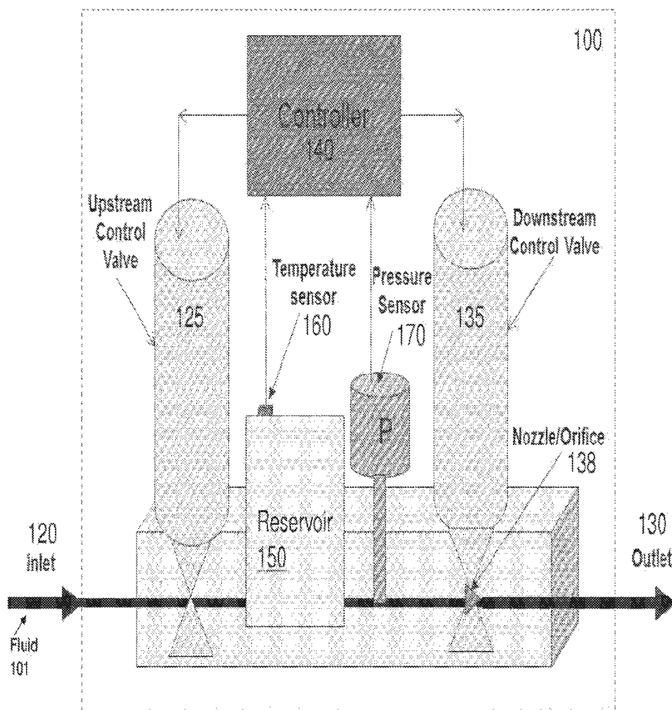


FIG. 1

**(57) Abstract**: A mass flow control system can be self verified for its accuracy when controlling a flow to a process. The system comprises a control valve for controlling the flow of fluid through the system as a function of control signal; a controller for generating the control signal as a function of measured flow of fluid through the system and a target flow set point; a pressure sensor for measuring the controlling fluid pressure for use in measuring and verifying the flow rate; and a source of fluid for providing a known volume of fluid for use in verifying the system accuracy anytime between steps of the control process.

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# METHOD AND APPARATUS FOR SELF VERIFICATION OF PRESSURED BASED MASS FLOW CONTROLLERS

## Field

**[0001]** The present disclosure relates generally to mass flow controllers, and more particularly to self verification of pressure based mass flow controllers. As used herein the term "gas" is considered to include a gas or vapor.

## Background

**[0002]** In general, a mass flow controller (MFC) controls and monitors the rate of fluid (i.e., a gas or vapor) flow in real time so that the flow rate of the mass of a gas passing though the device can be metered and controlled. Mass flow controllers (MFCs) are often used to control the flow of gases during a semiconductor manufacturing process wherein the flow of gases into a semiconductor tool, such as a vacuum chamber, must be carefully controlled in order to produce high yield semiconductor products. MFCs are usually designed and calibrated to control the flow rate of specific types of gas at particular ranges of flow rates. The devices control the rate of flow based on a given set point, usually predetermined by the user or an external device such as the semiconductor tool itself. The set point can be changed with each step of a process depending on the desired flow rate for each step. MFCs can be either analog or digital. They are typically designed to be used with pressure ranges of the inlet gases, with low pressure and high pressure MFCs being typically available. All MFCs have an inlet port, and outlet port, a mass flow meter including a mass flow sensor and a proportional control valve. A system controller is used as a part of a feedback control system that provides a control signal to the control valve as a function of a comparison of the flow rate as determined by the set point with the measured flow rate as sensed by the mass flow sensor. The feedback control system thus operates the valve so that the measured flow is maintained at the flow rate as determined by the set point.

**[0003]** Such control systems assume that the MFC remains in calibration within certain tolerances. In order to test whether a MFC is within the tolerances of



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calibration, the MFC is typically tested off line with such devices as mass flow verifiers. The latter are used to test the flow rates. While off line testing is very accurate, there is always a problem that a MFC can become out of calibration during the running of a process (in real time), and not be detected until the process is completed. Often this can result in lower yields of semiconductor product, and even a complete failure resulting in the loss of the entire product yield. This can be expensive, and is clearly undesirable. What is needed is a system and method for continually testing the accuracy of a MFC in real time while processes are being run.

**[0004]** Mass flow controllers include two types, thermal-based and pressure-based mass flow controllers. U.S. Patent Application Serial No. 13/354,988 filed January 20, 2012 in the name of Junhua Ding, entitled "System and Method of Monitoring Flow Through Mass Flow Controllers in Real Time"; and assigned the present assignee, describes a system and method for testing a thermal-based mass flow controller so that the accuracy of the mass flow controller can be verified without going off line.

Summary

**[0005]** Certain embodiments of the present invention relate to a mass flow control system whose accuracy can be self verified in real time when controlling a flow of a fluid to a process, the system comprising:

a control valve for controlling the flow of fluid through the system as a function of a control signal;

a controller for generating the control signal as a function of measured flow of fluid through the system and a set point; and

a source of fluid for providing a known volume of fluid for use in verifying the accuracy of the system anytime between steps of the flow control process. In one implementation, the system further includes a flow restrictor to generate chocked flow condition for flow measurement; a pressure sensor for providing a pressure measurement signal representative of the measured pressure of fluid upstream to the flow restrictor in the system; and a temperature sensor for providing a temperature measurement signal representative of the measured temperature of fluid in the system.



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In another implementation, the system further includes a second pressure sensor for providing a pressure measurement signal representative of the measured pressure of fluid downstream to the flow restrictor such that the flow rate can be measured for non-chocked flow condition.

**[0006]** In accordance with another implementation, a method of verifying the accuracy of a mass flow control system when controlling a flow to a process is provided. The method comprises: controlling the flow of fluid through the system as a function of a control signal; generating the control signal as a function of measured flow of fluid through the system and a set point; and providing a known volume of fluid for use in verifying the accuracy of the system anytime between steps of the flow control process.

General Description of the Drawings

**[0007]** The drawing figures depict one or more implementations in accord with the present teachings, by way of example only, not by way of limitation. In the figures, like reference numerals refer to the same or similar elements.

**[0008]** Fig. 1 is a general schematic diagram of one embodiment of a pressure-based MFC configured to allow testing of the accuracy of the MFC without going off line; and

**[0009]** Fig. 2 is a general schematic diagram of a second embodiment of a pressure-based MFC configured to allow testing for the accuracy of the MFC without going off line.

Detailed Description of the Drawings

**[00010]** In the following detailed description, numerous specific details are set forth by way of examples in order to provide a thorough understanding of the relevant teachings. However, it should be apparent to those skilled in the art that the present teachings may be practiced without such details. In other instances, well known methods, procedures, components, and/or circuitry have been described at a relatively high-level, without detail, in order to avoid unnecessarily obscuring aspects of the present teachings.

**[00011]** It is understood that other configurations of the subject technology will become readily apparent to those skilled in the art from the following detailed description, wherein various configurations of the subject technology are shown and described by way of illustration. As will be realized, the subject technology is capable of other and different configurations and its several details are capable of modification in various other respects, all without departing from the scope of the subject technology. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not as restrictive.

**[00012]** The present disclosure relates to a pressure-based MFC. There are two embodiments, one is used for choked flow conditions, and the other for non-choked flow conditions. As will be seen, one device can be configured to operate in either mode.

**[00013]** Choked flow is a compressible flow effect. The parameter that becomes "choked" or limited is the velocity of the fluid. Choked flow is thus a fluid dynamic condition in which a fluid flowing through the MFC at a given pressure and temperature will increase in velocity as it passes through a restriction (such as an orifice of fixed cross sectional area or a nozzle ) into a lower pressure environment. Choked flow is a limiting condition which occurs when the mass flow rate will not increase with a further decrease in the downstream pressure environment while upstream pressure is fixed. Under choked flow conditions, the mass flow rate can be increased by increasing the upstream pressure, or by decreasing the upstream temperature. The choked flow of gases is useful in many applications because the mass flow rate is independent of the downstream pressure, depending only on the temperature and pressure on the upstream side of the restriction. Under choked flow conditions, flow restrictive devices, such as valves, calibrated orifice plates and nozzles can be used to produce a desired mass flow rate. For chocked flow condition, the upstream pressure *Pu* and the downstream pressure *Pd* to the flow restrictor must satisfy the following criterion:

$$\frac{P_d}{P_u} \le \left(\frac{2}{\gamma + 1}\right)^{\gamma/(\gamma-1)} \quad (1)$$

**[00014]** Where γ is the specific heat ratio of the gas.



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[00015] As shown in FIG. 1, an embodiment of the new pressure based MFC 100 is configured (a) for choke flow conditions and (b) to provide information enabling verification of the accuracy of the MFC in real time. The MFC 100 receives fluid 110 at an inlet port 120 of MFC 100. The fluid is directed from the inlet port through a conduit 130 of a support block 140 to an outlet port 150. The upstream portion of the block 140 of MFC 100 supports an upstream proportional control valve 160 configured to regulate the flow rate of the fluid 110 through the outlet 150 of the MFC 100 in response to and as a function of a flow control signal applied to the upstream valve. Specifically, the upstream control valve 160 is operable in any position between a fully opened and fully closed position as a function of and in response to a flow control signal from the controller 170 so as to control the flow rate of the fluid 110 from the outlet 150 of the MFC. The flow control signal is generated by controller 170 as a function of a (a) set flow signal shown applied to the controller 170 and representing the desired (flow set point) flow rate of fluid through the MFC (set by a user and/or an external program from an external device such as a stand alone computer or a process tool), and (b) a measured flow signal representing the measured flow rate which is a function of the pressure and temperature of the fluid flowing through the MFC. Controller 170 includes memory for storing calibration coefficients necessary to provide an accurate measured flow signal based the sensed temperature and pressure signals received by the system. In the embodiment shown, this measure flow signal is provided as a function of a pressure signal provided by the pressure sensor 180 (shown in Fig. 1 in the form of a pressure transducer), and a temperature signals provided by a temperature sensor 190. The outlet 150 of the MFC 100 is provided with some type of flow restriction indicated at 200, which can be provided by the downstream control valve 210 (by controlling the position of the valve so as to create a restrictive opening), or by a separate device, such as a flow nozzle/orifice which has the effect of limiting the flow and pressure of the fluid flowing from the outlet 150 under choke flow conditions.

[00016] In order to verify the accuracy of the MFC in real time, the illustrated embodiment of Fig. 1, the MFC 100 also further includes the downstream control valve 210 supported by the block 140 at the outlet 150, and a reservoir 220. The reservoir 220 is supported by the block 140 between the two control valves 160 and 210. The reservoir is configured to store a known volume of fluid that flows into



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the MFC. The temperature sensor 190 is coupled to the reservoir 220 so that it measures the temperature of the wall of the reservoir, approximating the temperature of the fluid in the reservoir 220 and thus the fluid flowing in the MFC. The temperature sensor 190 provides to the controller 170 a signal representative of the measured temperature. The measured flow rate is a function of this measure temperature, as well as the pressure as measured by the pressure sensor 180. Pressure sensor 180 is also coupled with the conduit 130, between the two valves 160 and 210, and configured to measure the pressure of the fluid 110 flowing through the conduit 130 to the flow restrictor shown as an orifice 200 of the downstream control valve 210.

**[00017]** During operation of a process, the downstream control valve 210 is open, and the flow set point is set at a non-zero value, causing the controller 170 to control the flow through the upstream valve 160 so that the measured flow will equal the non-zero set value. Data representing the sensed temperature and pressure is transmitted, in the form of signals from the temperature sensor 190 and the pressure sensor 180, to the controller 170 for use in determining the measured mass flow flowing through the MFC. As described in greater detail below, the controller 170 determines the measured flow rate based on Equation (2) for a chocked flow condition:

$$Q_p = C' \cdot A \cdot f(m, \gamma, T) \cdot P_u, \qquad (2)$$

Where $C'$ is the orifice discharge coefficient of orifice 200, $A$ the effective orifice area, $m$ the molecular weight of the gas, $\gamma$ the specific heat capacity ratio of the gas, $T$ the gas temperature, $Pu$ the upstream pressure, and $f(m, \gamma, T)$ a mathematic function which is related to the gas molecular weight $m$, the specific heat capacity of the gas $\gamma$, and the gas temperature $T$.

**[00018]** The controller 170 provides valve control signals to the valve 160 for controlling the flow into and out of the MFC 100 so that the measured flow rate $Q_p$ tracks the flow commanded by the flow set point. The two will remain substantially equal (within allowed tolerances) so long as the MFC is properly



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calibrated. Where valve 210 is used to define the orifice of the flow restrictor, during choke flow conditions, the position of valve 210 will remain unchanged.

**[00019]** A flow verification check can be performed anytime a zero set point is commanded, as for instance the period between two steps of a gas delivery process, or following the completion of the process. During the flow verification period, the controller 170 automatically closes the upstream proportional control valve 160 allowing the controller 170 to verify the flow rate based on the rate of decay of the pressure signal provided by the pressure sensor 170 as the fluid continues to flow from the reservoir 220 (which is at a higher pressure than the pressure downstream of the MFC). This verification period typically requires about 100-300 msec to perform the measurement. In certain embodiments, the verification period may be between 100 to 300 milliseconds. During this verification period, fluid 110 from the reservoir 220 is directed out the outlet 150 of the MFC 100. The flow rate determined by the rate of decay principle, $Q_v$, which is indicative of the flow rate at which the remaining fluid 110 is exiting the system, can be determined by Equation (3):

$$Q_v = -k \cdot V \cdot \frac{d(P_u / T)}{dt}, \qquad (3)$$

where $t$ denotes time, k denotes a conversion constant and $V$, $P_u$, and $T$ respectively denote the volume of the reservoir 220, pressure of the gas as measured by the pressure sensor 170, and temperature of the gas as measured by the temperature sensor 160.

**[00020]** Once the verification period is over, downstream proportional control valve 210 is completely closed to prevent any remaining fluid 110 from exiting the MFC 100. During the verification period, MFC 100 verifies the calculated flow rate $Q_p$ using Equation (2) against the rate of decay flow rate, $Q_v$ as determined in accordance with Equation (3).

**[00021]** If the deviation of $Q_p$ from $Q_v$ is above a predetermined accuracy tolerance limit, the MFC 100 can send out an alarm to the host controller (not shown) to warn of the out of calibration condition. Alternatively, the MFC 100 can mathematically adjust or update the coefficients such as $C'$ *and/or* $A$ in the flow calculation Equation (2) based on the verified value of $Q_v$ such that the flow error between $Q_p$ and $Q_v$ is minimized, at or below the predetermined accuracy tolerance limit. Hence, the MFC 100 is recalibrated within the tolerance limits during the flow verification period. Thus, once adjusted, when a non-zero condition is subsequently commanded, the MFC 100 uses the verified value of the flow rate to achieve the target flow rate, at which the fluid exits the system.

**[00022]** Fig. 2 shows an embodiment for operating the MFC for non-choke flow conditions. Specially, the MFC 250 includes the same or similar components as the Fig. 1 embodiment, but with an additional pressure sensor 260 (shown as a pressure transducer) arranged to sense the pressure of the gas downstream from the flow restrictor 200. The second pressure sensor 260 can be mounted to block 140, or mounted separate from the block.

**[00023]** It should be appreciated that the embodiment of Fig. 2 can be used for both choked flow conditions and non-choked flow conditions. The mode of operation of the Fig. 2 embodiment is thus determined whether the MFC 250 is to be operated for choked flow conditions or non-choked flow conditions.

**[00024]** For non-choked conditions, the measured flow rate is calculated by Equation (4) as

$$Q_p = f(P_u, P_d, T, m, \gamma, A), \tag{4}$$

Wherein $f$ is a mathematic function of the upstream pressure $P_u$, the downstream pressure $P_d$, the gas temperature $T$, the gas molecular weight $m$, the gas specific heat ratio $\gamma$ *and* the effective office area $A$.

**[00025]** During flow under non-choked flow conditions, for verification the upstream valve is again closed and gas will then flow from the reservoir 220 and

out the outlet 150 (downstream from the valve 260) of the MFC 250. The verified flow rate, $Q_v$, is still determined by Equation (3) above.

**[00026]** Data relating to the values of $Q_p$ and $Q_v$ can be accumulated in the controller 170 and the data related to $Q_p$ and $Q_v$ can then be compared to determine whether the MFC is out of certain calibration tolerances. Further, the coefficients in Equation (4) can be updated to minimize the flow error between $Q_v$ and $Q_p$. Hence, the MFC 250 is recalibrated during the flow verification period.

**[00027]** Accordingly, the foregoing is a system and method for continually testing and verifying the calibration settings of a MFC in real time while processes are being run. In one additional implementation, the system can also do self-calibration by adjusting the flow calculation coefficients based on the verification results if there are differences between the current coefficients stored in the memory of the controller 170, and coefficients determined from the measurements made by the system. In such an arrangement, the coefficients of a flow calculation equation for the measured flow rate $Q_p$ can be recalculated based on the verification results such that the flow error between $Q_p$ and $Q_v$ is minimized, at or below a predetermined accuracy tolerance limit so as to recalibrate the system within the tolerance limits during the flow verification period.

**[00028]** Since other changes and modifications may be made in the above-described apparatuses and processes without departing from the scope of the invention herein involved, it is intended that all matter contained in the above-description shall be interpreted in an illustrative and not in a limiting sense.

What is claimed is:

1. A mass flow control system whose accuracy can be self verified in real time when controlling a flow of a fluid to a process, the system comprising:

a control valve for controlling the flow of fluid through the system as a function of a control signal;

a controller for generating the control signal as a function of measured flow of fluid through the system and a set point; and

a source of fluid for providing a known volume of fluid for use in verifying the accuracy of the system anytime between steps of the flow control process.

2. A mass flow control system according to claim 1, further including a flow restrictor for creating choked flow conditions for the flow of fluid through the system.

3. A mass flow control system according to claim 2, wherein the flow restrictor has an orifice whose cross sectional area is adjustable.

4. A mass flow control system according to claim 2, further including a second control valve for providing an adjustable opening that defines the flow restrictor.

5. A mass flow control system according to claim 1, further including a pressure sensor configured to provide a pressure measurement signal representative of the measured pressure of fluid in the system; and a temperature sensor configured to provide a temperature measurement signal representative of the measured temperature of fluid in the system.

6. A mass flow control system according to claim 5, wherein the controller is configured to determine the measured flow of fluid $Q_p$ through the system as a function of the measured pressure and temperature of the fluid in the system as

$$Q_p = C' \cdot A \cdot f(m, \gamma, T) \cdot P_u,$$



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Where $C'$ is the orifice discharge coefficient of the flow restrictor, $A$ the effective orifice area of the flow restrictor, $m$ the molecular weight of the gas, $\gamma$ the specific heat capacity ratio of the gas, $T$ the gas temperature, $P_u$ the upstream pressure, and $f(m, \gamma, T)$ a mathematic function which is related to the gas molecular weight, the specific heat capacity of the gas, and the gas temperature.

7. A mass flow control system according to claim 1, wherein the source of fluid is a reservoir of known volume positioned downstream from the control valve such that the control valve is closed when a zero flow set point is commanded, and fluid is still allowed to flow from the reservoir and measured by the system based on chocked flow condition $Q_p$, wherein another flow measurement $Q_v$ can be made by the rate of decay of the fluid from the reservoir as

$$Q_v = -k \cdot V \cdot \frac{d(P_u/T)}{dt},$$

where $t$ denotes time, k denotes a conversion constant and $V$, $P_u$, and $T$ respectively denote the volume of the reservoir, the pressure and temperature of the gas in the reservoir.

8. A mass flow control system according to claim 7, wherein the system can self verify its flow accuracy as a function of any differences between flow measurement made by the rate of decay of the fluid from the reservoir $Q_v$, and the flow rate measured by the system based on chocked flow condition $Q_p$.

9. A mass flow control system according to claim 7, further including a second valve wherein the second control valve is closed to fulfill the zero flow set point command after the flow verification is completed.

10. A mass flow control system according to claim 7, wherein verification occurs during a verification period anytime between steps of the flow control process, the verification period being between 100 and 300 milliseconds.

11. A mass flow control system according to claim 7, wherein the reservoir is positioned between the control valve and the flow restrictor.

12 A mass flow control system according to claim 7, wherein the system provides an alarm to a host controller to warn of an out of calibration condition if the deviation of $Q_p$ from $Q_v$ is above a predetermined accuracy tolerance limit.

13 A mass flow control system according to claim 7, wherein the system can adjust the coefficients of flow calculation equation for the measured flow rate $Q_p$ based on the verification results such that the flow error between $Q_p$ and $Q_v$ is minimized, at or below the predetermined accuracy tolerance limit so that the system is recalibrated within the tolerance limits during the flow verification period.

14. A mass flow control system according to claim 1, further including a flow restrictor, a first pressure sensor for generating a signal as a function of the pressure of the fluid upstream from the flow restrictor and a second pressure sensor for generating a signal as a function of the pressure of fluid downstream from the flow restrictor for measure the flow of fluid during non-choke flow conditions, where the measured flow rate $Q_p$ is based on the following equation:

$$Q_p = f(P_u, P_d, T, m, \gamma, A),$$

Wherein f is a mathematic function of the upstream pressure $P_u$, the downstream pressure $P_d$, the gas temperature $T$, the gas molecular weight $m$, the gas specific heat ratio $\gamma$ and the effective office area $A$.

15. A method of verifying the accuracy of a mass flow control system when controlling a flow to a process, the method comprising:

controlling the flow of fluid through the system as a function of a control signal;

generating the control signal as a function of measured flow of fluid through the system and a set point; and

providing a known volume of fluid for use in calibrating the system anytime between steps of the flow control process.

16. A method according to claim 15, wherein controlling the flow of fluid includes controlling the flow of fluid through a flow restrictor so as to create choked flow conditions.

17. A method according to claim 16, wherein controlling the flow through a flow restrictor includes controlling the flow through an orifice whose cross sectional area is adjustable.

18. A method according to claim 16, wherein controlling the flow through a flow restrictor includes controlling the flow through a second control valve for providing an adjustable opening that defines the flow restrictor.

19. A method according to claim 15, further including providing a pressure measurement signal representative of the measured pressure of fluid in the system; and providing a temperature measurement signal representative of the measured temperature of fluid in the system.

20. A method according to claim 19, further including determining the measured flow of fluid $Q_p$ through the system as a function of the measured pressure and temperature of the fluid in the system as

$$Q_p = C' \cdot A \cdot f(m, \gamma, T) \cdot P_u,$$

Where *C'* is the orifice discharge coefficient of the flow restrictor, *A* the effective orifice area of the flow restrictor, *m* the molecular weight of the gas, $\gamma$ the specific heat capacity ratio of the gas, *T* the gas temperature, *Pu* the upstream pressure, and $f(m, \gamma, T)$ a mathematic function which is related to the gas molecular weight, the specific heat capacity of the gas, and the gas temperature.

21. A method according to claim 15, further including providing a source of fluid from a reservoir of known volume positioned downstream from a control valve such that the control valve is closed when a zero flow set point is commanded, and allowing fluid to still be allowed to flow from the reservoir and measured by the system based on chocked flow condition $Q_p$, wherein another flow measurement $Q_v$ can be made by the rate of decay of the fluid from the reservoir as

$$Q_v = -k \cdot V \cdot \frac{d(P_u / T)}{dt},$$

where *t* denotes time, k denotes a conversion constant and $V$, $P_u$, and $T$ respectively denote the volume of the reservoir, the pressure and temperature of the gas in the reservoir.



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22. A method according to claim 21, further including self-verifying system flow accuracy as a function of the any differences between flow measurement made by the rate of decay of the fluid from the reservoir $Q_v$ , and the flow rate measured by the system based on chocked flow condition $Q_p$.

23 A method according to claim 21, further including closing a second control valve to fulfill the zero flow set point command after the flow verification is completed.

24. A method according to claim 21, wherein verification occurs during a verification period anytime between steps of the flow control process, the verification period being between 100 and 300 milliseconds.

25. A method according to claim 21, wherein the reservoir is positioned between a control valve and a flow restrictor.

26 A method according to claim 21, further including sending an alarm to a host controller to warn of an out of accuracy condition if the deviation of $Q_p$ from $Q_v$ is above a predetermined accuracy tolerance limit.

27 A method according to claim 21, further including adjusting the coefficients of a flow calculation equation for the measured flow rate $Q_p$ based on the verification results such that the flow error between $Q_p$ and $Q_v$ is minimized, at or below the predetermined accuracy tolerance limit so as to recalibrate the system within the tolerance limits during the flow verification period.

28. A method according to claim 15, further including generating a signal as a function of the pressure of the fluid upstream from a flow restrictor, and generating a signal as a function of the pressure of fluid downstream from the flow restrictor for measuring the flow of fluid during non-choke flow conditions, where the measured flow rate $Q_p$ is based on the following equation:

$$Q_p = f(P_u, P_d, T, m, \gamma, A),$$

Wherein $f$ is a mathematic function of the upstream pressure $P_u$, the downstream pressure $P_d$, the gas temperature $T$, the gas molecular weight $m$, the gas specific heat ratio $\gamma$ and the effective office area $A$.

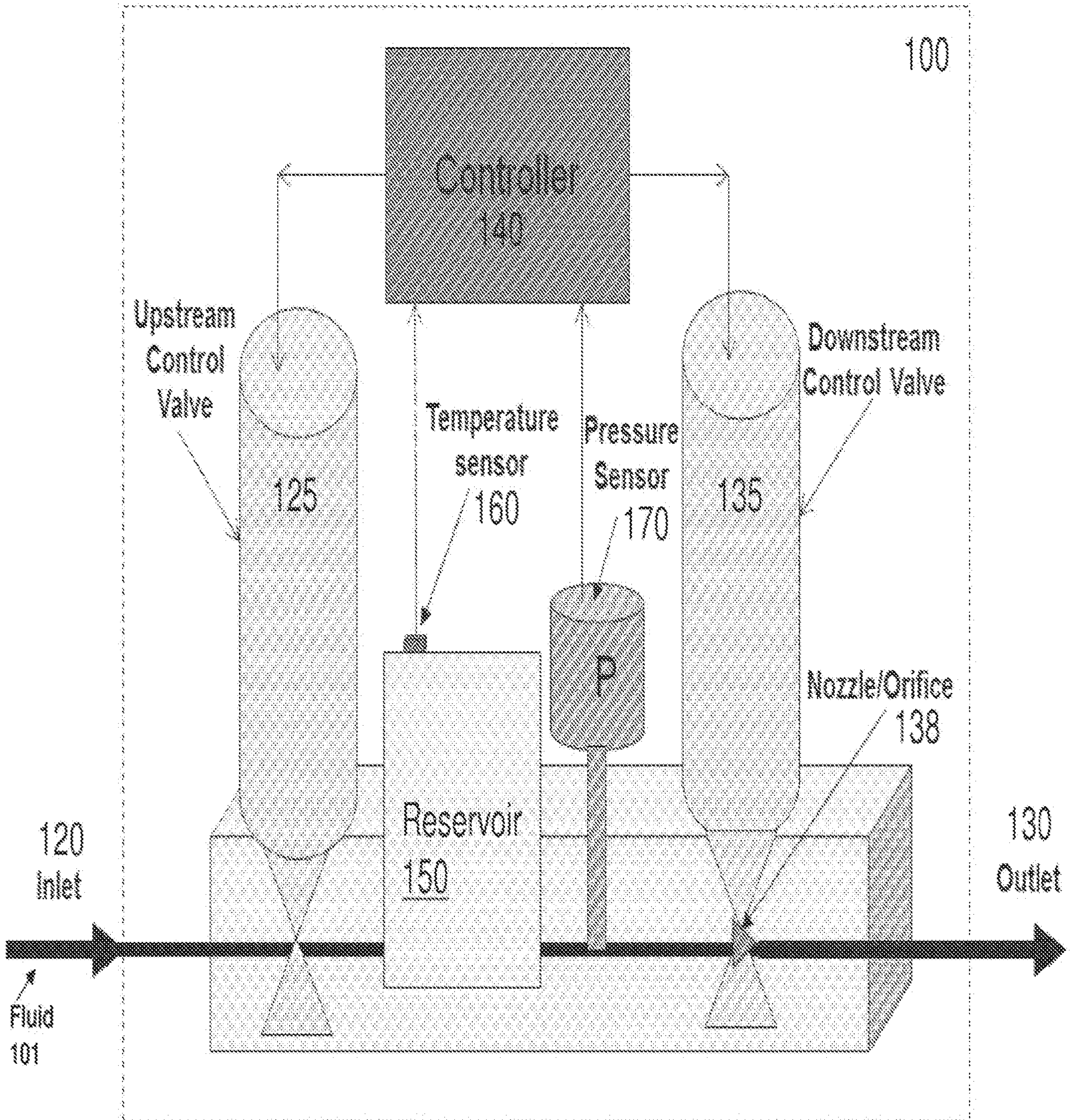


FIG. 1

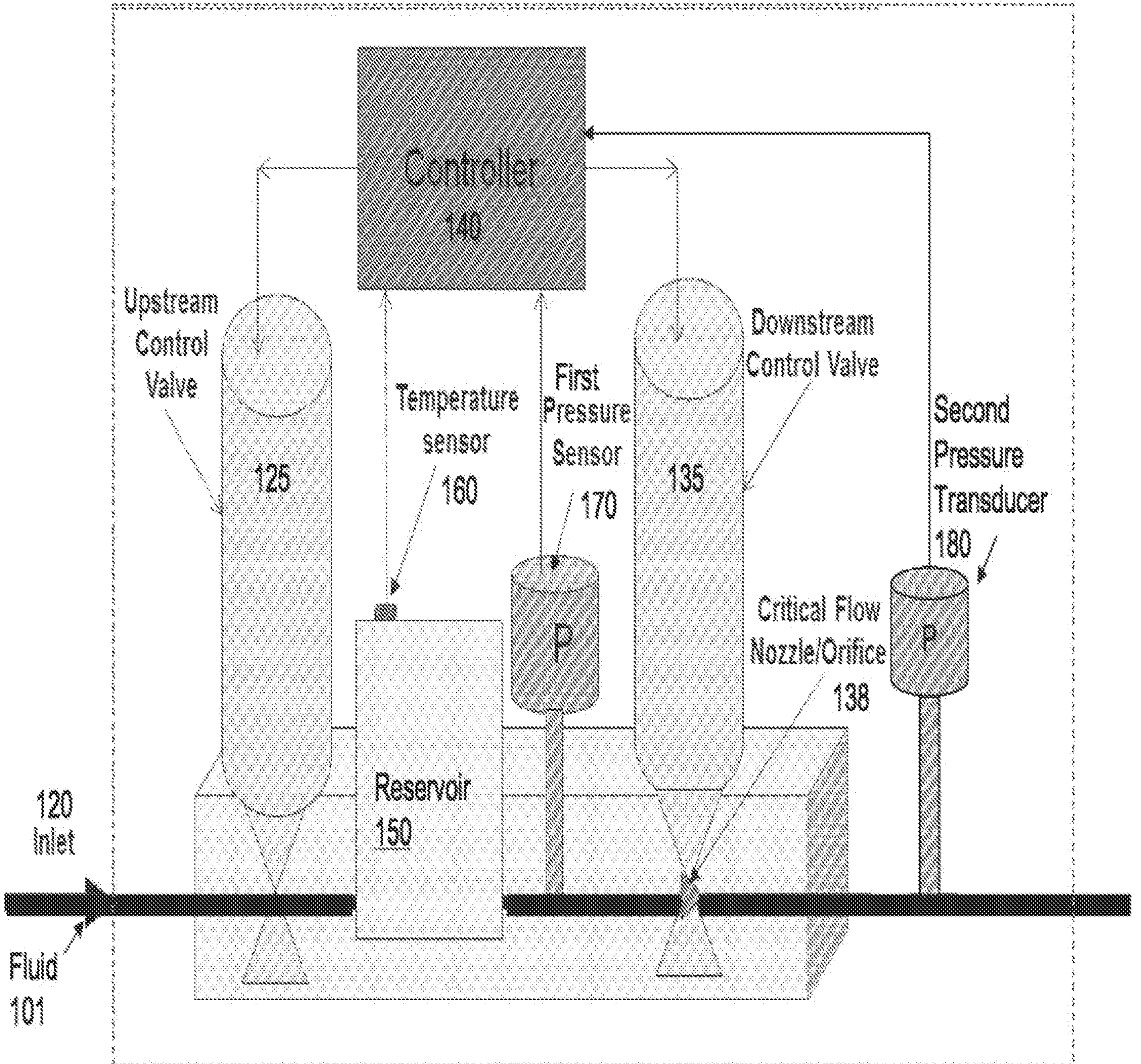


FIG. 2

# INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/057184

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. G05D7/06 G01F25/00 G01F1/74
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
G05D G01F

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

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

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | WO 2011/047361 A1 (PIVOTAL SYSTEMS CORP [US]; MONKOWSKI ADAM J [US]; CHALMERS JAMES MACAL) 21 April 2011 (2011-04-21) | 1-5, 15-19 |
| Y | the whole document | 6-14, 20-28 |
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| Y | the whole document | 6-14, 20-28 |
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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