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(54) **METHOD AND APPARATUS FOR CONTROLLING A PROCESSING SYSTEM**

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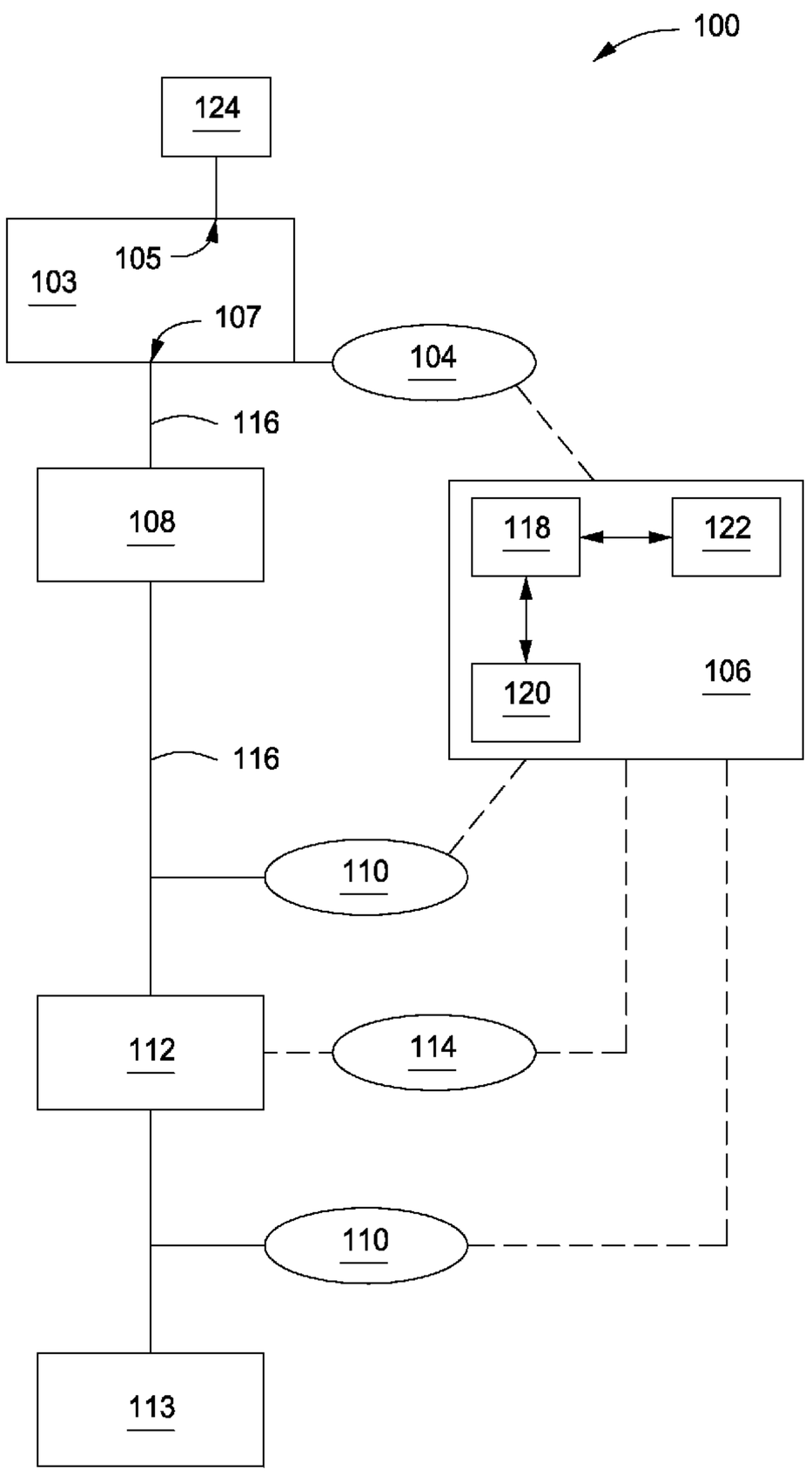
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(52) **U.S. Cl.** ..... **137/14**

(57) **ABSTRACT**

Methods and apparatus for controlling a processing system are provided herein. In some embodiments, a method of controlling a processing system may include operating a vacuum pump coupled to a process chamber at a first baseline pump idle speed selected to maintain the process chamber at a pressure equal to a first baseline pump idle pressure; monitoring the pressure in the process chamber while operating the vacuum pump at the first baseline pump idle speed; and determining whether the first baseline pump idle pressure can be maintained in the process chamber when the vacuum pump is operating at the first baseline pump idle speed.



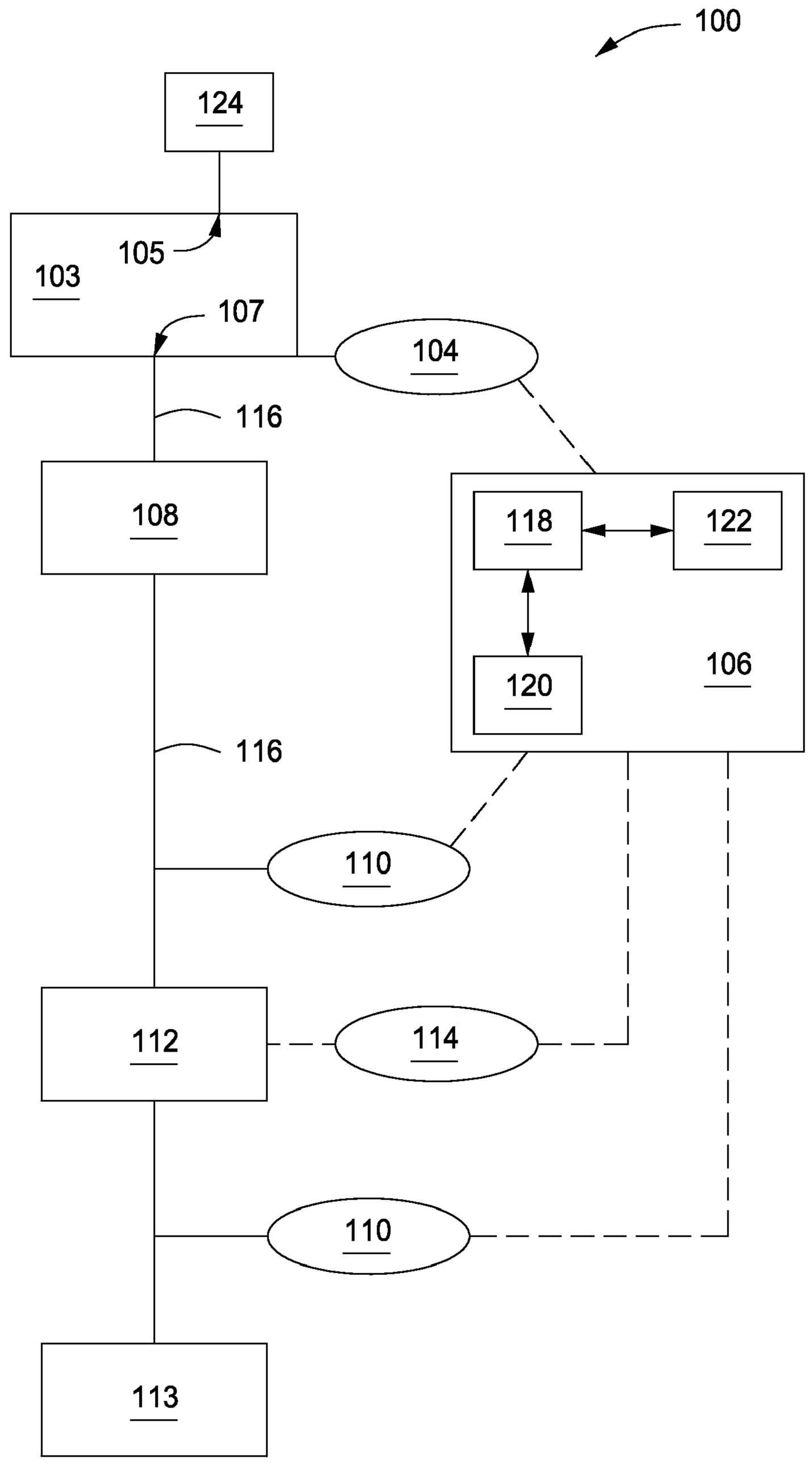

100
124
105
103
107
104
116
108
118
122
120
106
116
110
112
114
110
113

FIG. 1

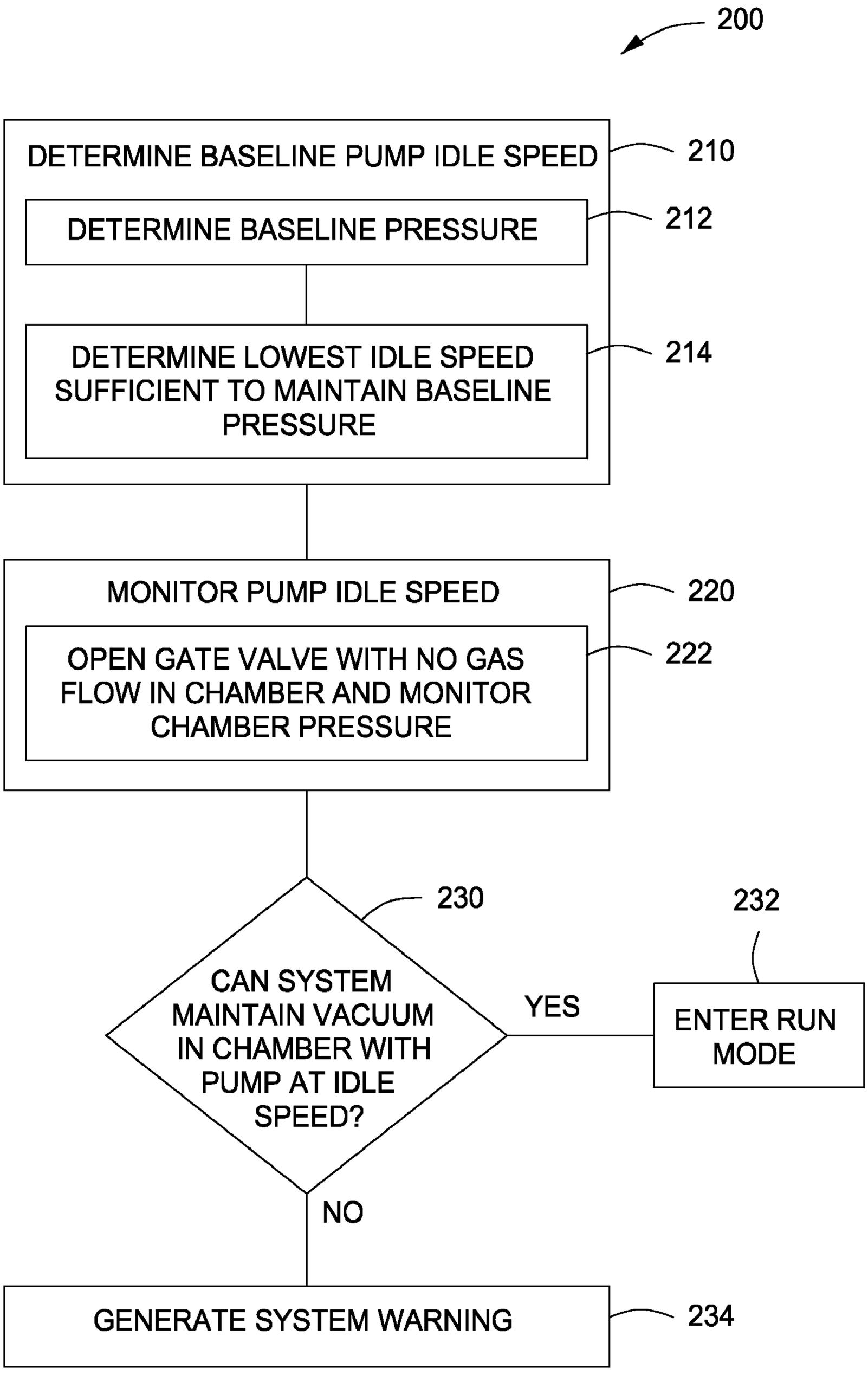

200
DETERMINE BASELINE PUMP IDLE SPEED
210
DETERMINE BASELINE PRESSURE
212
DETERMINE LOWEST IDLE SPEED SUFFICIENT TO MAINTAIN BASELINE PRESSURE
214
MONITOR PUMP IDLE SPEED
220
OPEN GATE VALVE WITH NO GAS FLOW IN CHAMBER AND MONITOR CHAMBER PRESSURE
222
230
CAN SYSTEM MAINTAIN VACUUM IN CHAMBER WITH PUMP AT IDLE SPEED?
YES
232
ENTER RUN MODE
NO
GENERATE SYSTEM WARNING
234

FIG. 2

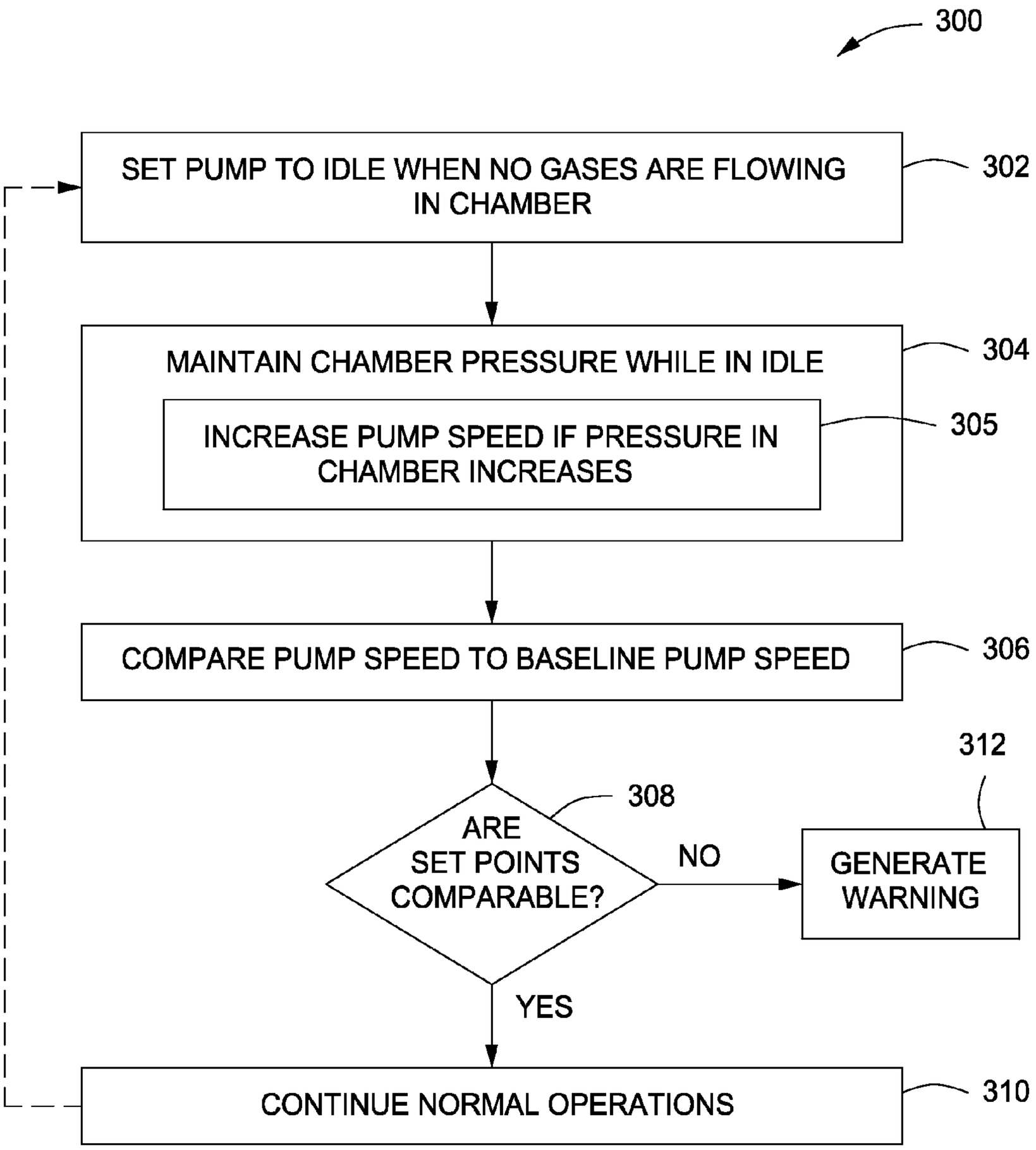

300
SET PUMP TO IDLE WHEN NO GASES ARE FLOWING IN CHAMBER
302
MAINTAIN CHAMBER PRESSURE WHILE IN IDLE
304
INCREASE PUMP SPEED IF PRESSURE IN CHAMBER INCREASES
305
COMPARE PUMP SPEED TO BASELINE PUMP SPEED
306
ARE SET POINTS COMPARABLE?
308
NO
GENERATE WARNING
312
YES
CONTINUE NORMAL OPERATIONS
310

FIG. 3

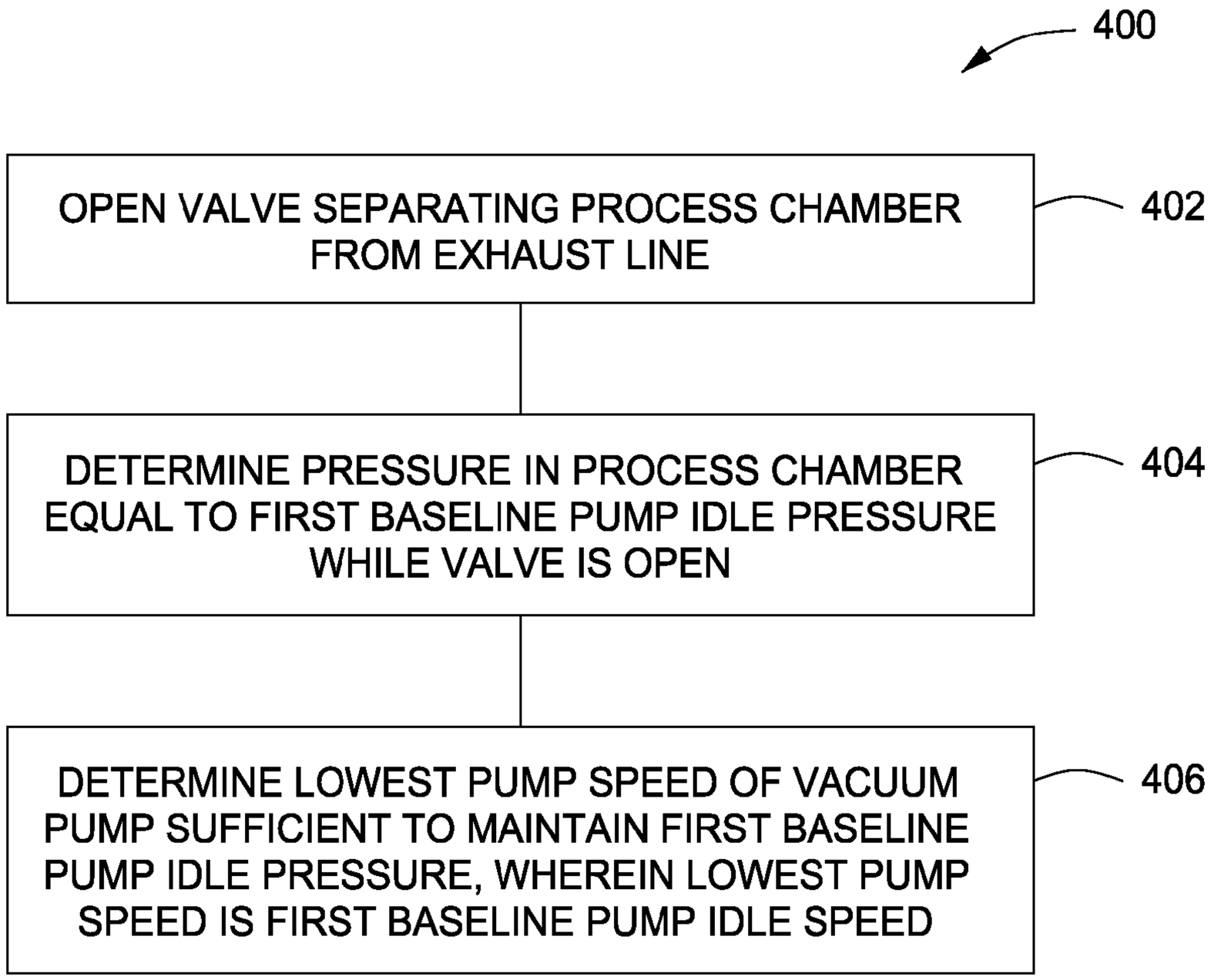

400
OPEN VALVE SEPARATING PROCESS CHAMBER FROM EXHAUST LINE
402
DETERMINE PRESSURE IN PROCESS CHAMBER EQUAL TO FIRST BASELINE PUMP IDLE PRESSURE WHILE VALVE IS OPEN
404
DETERMINE LOWEST PUMP SPEED OF VACUUM PUMP SUFFICIENT TO MAINTAIN FIRST BASELINE PUMP IDLE PRESSURE, WHEREIN LOWEST PUMP SPEED IS FIRST BASELINE PUMP IDLE SPEED
406

FIG. 4

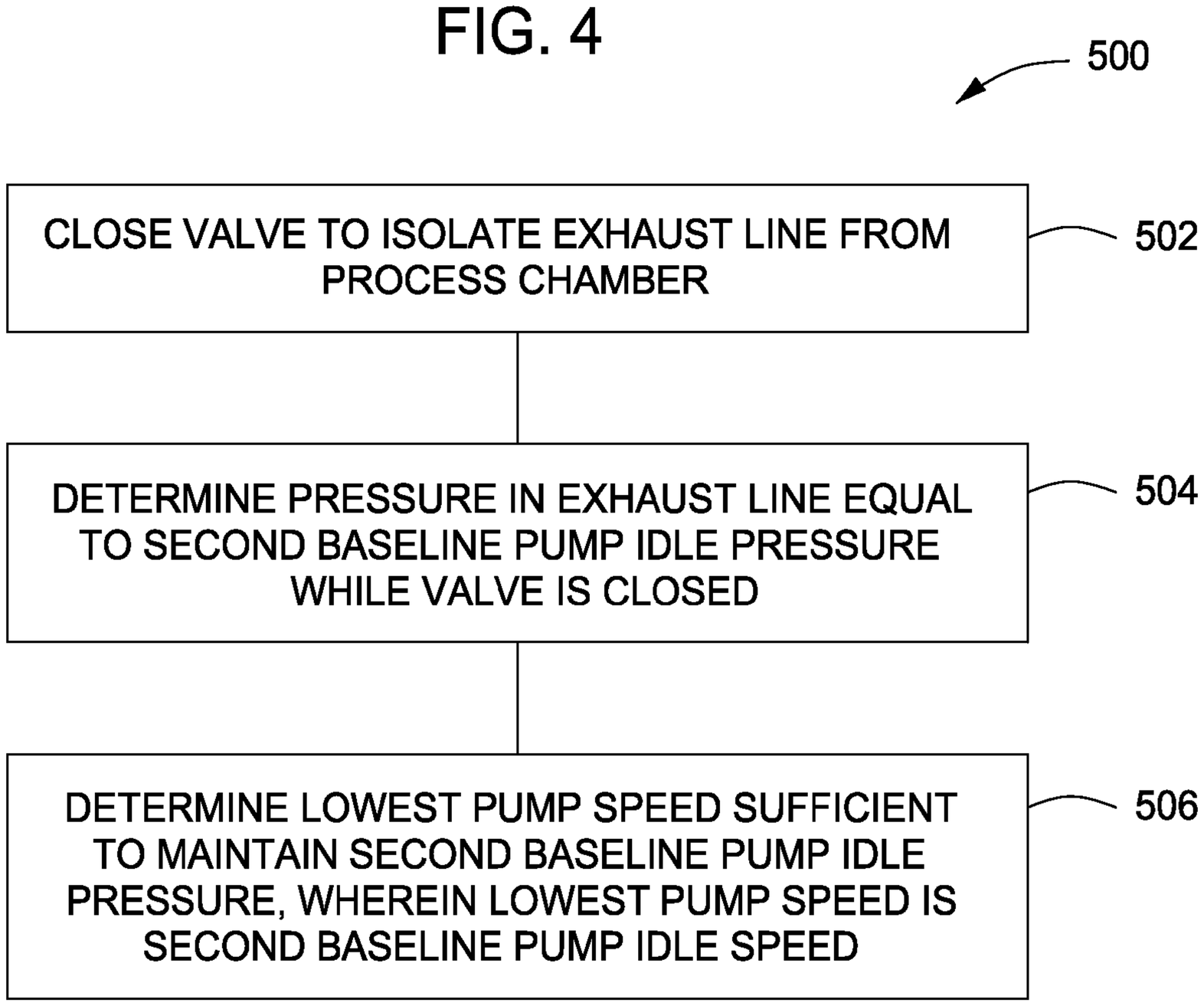

500
CLOSE VALVE TO ISOLATE EXHAUST LINE FROM PROCESS CHAMBER
502
DETERMINE PRESSURE IN EXHAUST LINE EQUAL TO SECOND BASELINE PUMP IDLE PRESSURE WHILE VALVE IS CLOSED
504
DETERMINE LOWEST PUMP SPEED SUFFICIENT TO MAINTAIN SECOND BASELINE PUMP IDLE PRESSURE, WHEREIN LOWEST PUMP SPEED IS SECOND BASELINE PUMP IDLE SPEED
506

FIG. 5

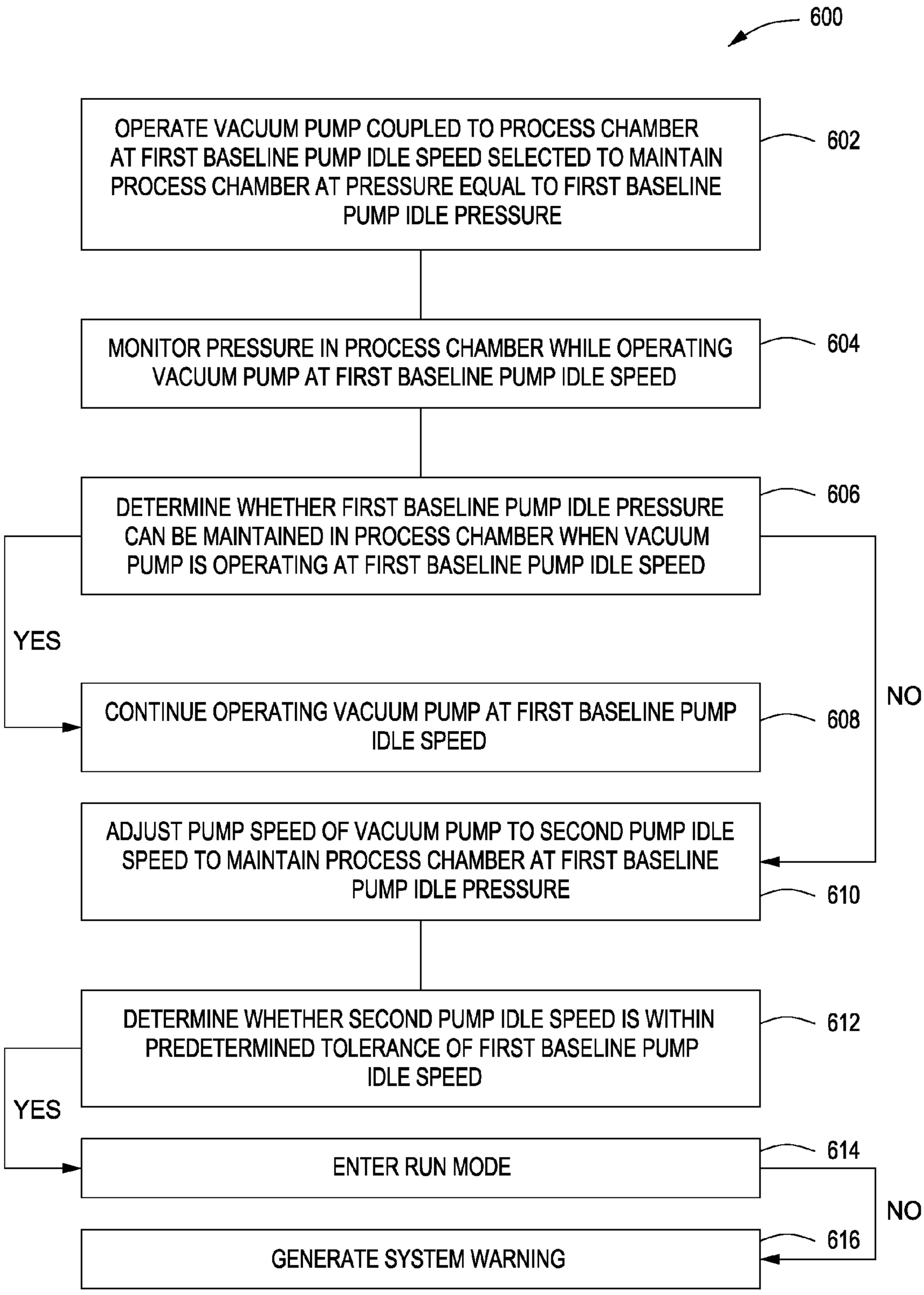

600
OPERATE VACUUM PUMP COUPLED TO PROCESS CHAMBER AT FIRST BASELINE PUMP IDLE SPEED SELECTED TO MAINTAIN PROCESS CHAMBER AT PRESSURE EQUAL TO FIRST BASELINE PUMP IDLE PRESSURE
602
MONITOR PRESSURE IN PROCESS CHAMBER WHILE OPERATING VACUUM PUMP AT FIRST BASELINE PUMP IDLE SPEED
604
DETERMINE WHETHER FIRST BASELINE PUMP IDLE PRESSURE CAN BE MAINTAINED IN PROCESS CHAMBER WHEN VACUUM PUMP IS OPERATING AT FIRST BASELINE PUMP IDLE SPEED
606
YES
NO
CONTINUE OPERATING VACUUM PUMP AT FIRST BASELINE PUMP IDLE SPEED
608
ADJUST PUMP SPEED OF VACUUM PUMP TO SECOND PUMP IDLE SPEED TO MAINTAIN PROCESS CHAMBER AT FIRST BASELINE PUMP IDLE PRESSURE
610
DETERMINE WHETHER SECOND PUMP IDLE SPEED IS WITHIN PREDETERMINED TOLERANCE OF FIRST BASELINE PUMP IDLE SPEED
612
YES
NO
ENTER RUN MODE
614
GENERATE SYSTEM WARNING
616

FIG. 6

# METHOD AND APPARATUS FOR CONTROLLING A PROCESSING SYSTEM

## CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application claims benefit of United States provisional patent application Ser. No. 61/442,277, filed Feb. 13, 2011, which is herein incorporated by reference.

## FIELD

**[0002]** Embodiments of the present invention generally relate to controls systems for vacuum processing equipment used, for example, in the manufacture of electronic devices.

## BACKGROUND

**[0003]** Electronics manufacturing facilities must maintain process chambers at appropriate operating pressures to maximize yield, throughput, uniformity, kit life, and up time. Additionally, electronics manufacturing facilities are significantly impacted by unscheduled down time, yield loss, and equipment damage related to line clogging, line leaks, reactive chemical incidents due to line leaks, and pump wear out. In current manufacturing facilities, inspection and maintenance of processing equipment related to the aforementioned problems are performed manually after such a problem occurs.

**[0004]** For example, conventional best-known methods (BKM) for leak checking of lines, line inspection for clogging, and pump capacity testing (running pump capacity curves between and after regularly scheduled preventative maintenance checks) take time, are difficult, require highly skilled labor, and are frequently not employed unless a pattern of significant incidents have occurred.

**[0005]** Solar and light emitting diode (LED) facilities are particularly impacted by these issues because difficulty of existing BKM procedures in finding leaks, defining the line clogging, and or pump wear time line out between normally scheduled replacement or inspection schedules.

**[0006]** Thus, the inventors have provided an improved monitoring and control systems for use in vacuum processing equipment.

## SUMMARY

**[0007]** Methods and apparatus for controlling a processing system are provided herein. In some embodiments, a method of controlling a processing system may include operating a vacuum pump coupled to a process chamber at a first baseline pump idle speed selected to maintain the process chamber at a pressure equal to a first baseline pump idle pressure; monitoring the pressure in the process chamber while operating the vacuum pump at the first baseline pump idle speed; and determining whether the first baseline pump idle pressure can be maintained in the process chamber when the vacuum pump is operating at the first baseline pump idle speed.

**[0008]** In some embodiments, the method may include upon monitoring a pressure in the process chamber that is different from the first baseline pump idle pressure, adjusting the pump speed of the vacuum pump to a second pump idle speed to maintain the process chamber at the first baseline pump idle pressure; and determining whether the second pump idle speed is within a predetermined tolerance of the first baseline pump idle speed.

**[0009]** In some embodiments, the method may include idling the vacuum pump when no gases are flowing in the process chamber; and monitoring the pressure in the process chamber while idling the vacuum pump at the first baseline pump idle speed.

**[0010]** In some embodiments, the method may be incorporated into a computer readable medium that, when executed, causes the method of controlling a processing system to be performed.

**[0011]** In some embodiments, a processing system may include a controller having one or more inputs to receive respective input values corresponding to a pressure in an interior volume of a process chamber and a pump speed of a vacuum pump coupled to the process chamber, wherein the controller is configured to receive the respective input values while the process chamber is in an idle mode, and wherein the controller is further configured to determine whether the process chamber can be maintained at a predetermined pressure corresponding to the vacuum pump operating at or within a predetermined tolerance of a baseline pump idle speed.

**[0012]** Other and further embodiments of the present invention are described below.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0013]** Embodiments of the present invention, briefly summarized above and discussed in greater detail below, can be understood by reference to the illustrative embodiments of the invention depicted in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

**[0014]** FIG. **1** depicts a schematic view of a processing system having a control system in accordance with some embodiments of the present invention.

**[0015]** FIG. **2** depicts a flow chart of a method **200** for controlling a processing system in accordance with some embodiments of the present invention.

**[0016]** FIG. **3** depicts a flow chart of a method **300** for controlling a processing system in accordance with some embodiments of the present invention.

**[0017]** FIG. **4** depicts a flow chart of a method **400** for determining a first baseline pump idle speed in accordance with some embodiments of the present invention.

**[0018]** FIG. **5** depicts a flow chart of a method **500** for determining a second baseline pump idle speed in accordance with some embodiments of the present invention.

**[0019]** FIG. **6** depicts a flow chart of a method **600** for controlling a processing system in accordance with some embodiments of the present invention.

**[0020]** To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. The figures are not drawn to scale and may be simplified for clarity. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

## DETAILED DESCRIPTION

**[0021]** Embodiments of the present invention generally relate to controls systems and methods for monitoring and controlling pump systems used in vacuum processing equipment, such as may be used in the manufacture of electronic

devices. For example, such control systems and methods may be used advantageously in equipment for manufacturing solar panels, silicon wafers and silicon-based semiconductor devices, liquid crystal displays (LCD), light emitting diodes (LED), and the like.

**[0022]** Embodiments of the present invention may provide an integrated controls solution using the vacuum pressure in the process chamber in a feedback control loop to dynamically change the pump speed (e.g., pump idle speed) of the pump to maintain a chamber pressure baseline (e.g., baseline pump idle pressure) and predict a need for a preventative maintenance (PM) downtime if degradation in the pressure is detected. In some embodiments, the present invention may be utilized while the chamber is in an idle mode, for example, when there are no processes being performed and/or no process gases flowing in the chamber. In the idle mode, the pump speed may be lower than during a production mode of the chamber.

**[0023]** FIG. **1** depicts a schematic view of a processing system **100** having a control system in accordance with some embodiments of the present invention. As shown in FIG. **1**, the processing system may generally include a process chamber **102** having an interior processing volume **103** and having one or more gas inlets **105** coupled to one or more gas sources **124** and an outlet **107** coupled to a vacuum pump **112** via an exhaust line **116**.

**[0024]** The one or more gas sources **124** may provide one or more gases to the process chamber **102**, such as process gases, cleaning gases, purge gases, or the like. The vacuum pump **112** is generally used to remove materials such as unused process gases, process byproducts, and the like from the process chamber. The vacuum pump **112**, in combination with a valve **108** disposed in the exhaust line **116** (such as a gate valve, a throttle valve, or the like), can also be used to control the pressure in the process chamber **102**. A first pressure sensor **104** (such as a pressure gauge) may be coupled to the process chamber **102** to sense the pressure within the process chamber **102**.

**[0025]** A controller **106** may be coupled to receive signals from the first pressure sensor **104** and a second pressure sensor **110** (discussed in more detail below). The controller **106** may be any suitable controller for use in an industrial setting. In some embodiments, the controller **106** may be a sub fab controller that is coupled to and controls various components within a sub fab of the substrate processing system **100**. In some embodiments the controller **106** may be a controller coupled to the process chamber **102**. Alternatively the controller **106** may be a separate controller configured as described herein.

**[0026]** The controller **106** may comprise a central processing unit (CPU) **118**, a memory **120**, and support circuits **122** for the CPU. The controller **106** may control each component of the processing system **100** directly, or via computers (or controllers) associated with particular process chamber and/or support system components. The controller **106** may be one of any form of general-purpose computer processor that can be used in an industrial setting for controlling various chambers and sub-processors. The memory, or computer-readable medium of the CPU may be one or more of readily available memory such as random access memory (RAM), read only memory (ROM), floppy disk, hard disk, flash, or any other form of digital storage, local or remote. The support circuits are coupled to the CPU for supporting the processor in a conventional manner. These circuits include cache, power supplies, clock circuits, input/output circuitry and subsystems, and the like. Inventive methods as described herein may be stored in the memory of the controller **106** as software routine that may be executed or invoked to control the operation of the substrate processing system **100** in the manner described herein. For example, each method step may be stored as or in a module of the memory **120**. The software routine may also be stored and/or executed by a second CPU (not shown) that is remotely located from the hardware being controlled by the controller **106**.

**[0027]** The controller **106** may be coupled to and communicate with the first pressure sensor **104**, the second pressure sensor **110**, and a pump controller **114**. The second pressure sensor **110** may be configured to sense a pressure in the line **116** between the valve **108** and the vacuum pump **112**. The second pressure sensor **110** can be located in any position between the valve **108** and the vacuum pump **112**, but is typically positioned near the vacuum pump inlet. Alternatively, the second pressure sensor **110** may be disposed between the vacuum pump **112** and an abatement system **113** for abating the process chamber exhaust such that the controller **106** may monitor inlet pressure on the abatement system **106**. The pump controller **114** is coupled to and controls the speed of the vacuum pump **112**. Pump controller can be a PLC (Programmable logical controller), a Micro controller, or in a case of a stripped down pump, variable frequency drive (VFD) and input/output (IO) modules controlled by the controller **106**. For example, the pump controller **114** could be integrated into the vacuum pump package and the set points could be driven from the controller **106**, or the pump controller could be a stand-alone unit receiving vacuum pump power, pump speed, inert flow, coolant flow, and operating temperature commands from the controller **106**. The pump controller **114** can optionally send signals to valves within the pump package to control the level of inert pump purge, pump rpm, pump power usage, pump coolant, and pump temperature. The control signals from the pump controller **114** may control the total inert gas addition and cooling water flow or optionally control the cooling water and inert gas addition by compression zone.

**[0028]** In operation, the controller **106** may dynamically control an idle speed setpoint of the pump speed of the vacuum pump **112** based on feedback from the pressure sensor **104**. In addition the controller **106** may detect degradation or leaks in the exhaust line **116** of the process chamber **102**. For example, in some embodiments, the controller **106** may receive a signal from the pressure sensor **104** correlating to the vacuum pressure in the process chamber **102** and may use that signal in a feedback control loop to dynamically change the pump speed (e.g., a pump idle speed) of the vacuum pump **112** to maintain a chamber pressure baseline (e.g., a baseline pump idle pressure) and to predict a need for a preventative maintenance downtime if degradation in the chamber pressure is detected.

**[0029]** FIG. **2** depicts a flow chart of a method **200** for controlling a processing system in accordance with some embodiments of the present invention. In some embodiments, the method **200** may be an example of a module of the memory **122** of the controller and may be used to control the processing system as described herein. The method **200** generally begins at **210** where a baseline pump idle speed is determined. For example, a baseline pump idle speed determiner module may be included the memory **122** of the controller and/or the memory of another controller, such as the

pump controller **114** for determining the base pump idle speed. In some embodiments, the baseline pump idle speed may be determined by first determining a baseline pump idle pressure of the exhaust line **116** downstream of the valve **108**. For example with the valve **108** closed, the pump may be run at full speed and the pressure within the exhaust line **116** may be measured with the second pressure sensor **110**. Next, at **214**, the lowest idle speed sufficient to maintain the baseline pump idle pressure may be determined. For example, the pump speed may be decreased to reach a baseline pump idle speed, defined as the lowest pump speed sufficient to maintain the baseline pump idle pressure. The baseline pump idle speed of the vacuum pump **112** provides the lowest energy consumption from running the vacuum pump **112** while maintaining the baseline pump idle pressure in the exhaust line **116** downstream of the valve **108**.

**[0030]** Next at **220**, the pump speed may be monitored while the vacuum pump is being operated at the baseline pump idle speed. For example, a pump speed monitor module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for monitoring pump speed. In some embodiments, as shown at **222**, the valve **108** may be opened with no gas flowing in the process chamber **102** and the chamber pressure may be monitored via the pressure sensor **104**. When the gate valve is opened in the gases flowing in the process chamber, the system should ideally remain sealed and the vacuum pump should be able to maintain a desired vacuum pressure within the process chamber **102**.

**[0031]** Next at **230**, it is determined whether the system can maintain vacuum (e.g., the baseline pump idle speed) in the process chamber **102** with the vacuum pump **112** running at the baseline pump idle speed. For example, a maintaining baseline pump idle pressure determiner module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for determining whether a pressure can be maintained while operating the pump **112** at the baseline pump idle speed. If it is determined that the system can maintain the vacuum pressure (e.g., the baseline pump idle speed) in the process chamber then the system can enter run mode, as shown at **232**. For example, a system run module may be included in the memory **122** and/or the memory of another controller, to cause the system to enter a run mode, or for providing a signal indicating that a run mode may be entered, when the maintaining baseline pump idle pressure determiner module determines that the system can maintain the baseline pump idle pressure. However, if the system cannot maintain the vacuum pressure in the process chamber, then a system warning may be generated. For example, a system warning module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for causing the system to generate a warning when maintaining baseline pump idle pressure determiner module determines that the system cannot maintain the baseline pump idle pressure. The system warning may include one or more of warning messages, lights, audible sounds, or the like. Warnings may be displayed with a flashing yellow light and/or a message on the operator interface (e.g., human machine interface, or HMI) of the controller **106**. Warning messages can provide further details on possible cause, such as pump degradation, leaks post or pre gate valve or in chamber. Warnings can be tied to the process tool controller and can prevent the next wafer load. For example, the controller **106** can display an appropriate warning message on the screen (e.g., leak, line clogging, pump wear out, or the like) and optionally can display a warning light, for example, on the sub fab equipment status light tower or other suitable location. The controller **106** may cause the alarm message, lights, audible sounds, etc., to be provided on the controller **106**, on a process chamber controller display (not shown), a factory controller display (not shown), or any other suitable location. Customer programmable escalation options could include auto shut down or implementation of interlocks to prevent a next cycle of substrate processing if warnings are not acknowledged and/or if the deficiency is not resolved. If a system warning is generated, the system may be shut down and any leaks along the exhaust conduit **116** between the valve **108** and the process chamber **102** may be located and fixed.

**[0032]** FIG. **3** depicts a flow chart of a method **300** for controlling a process chamber in accordance with some embodiments of the present invention. In some embodiments, the method **300** may be an example of a module of the memory **122** of the controller and may be used to control the processing system as described herein. In some embodiments, the method **300** may be performed after the method **200** has previously been performed. The method **300** generally begins at **302**, where the vacuum pump **112** may be set to idle mode when no gases are flowing in the process chamber **102**. For example, a vacuum pump idler module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for causing the vacuum pump to idle. For example, after processing of a substrate, or a number of substrates is completed, the process chamber may enter an idle mode to await further substrates, perform maintenance, or the like. When the process chamber is in an idle state, or at some other desired period of time when no gases are flowing in the process chamber, the speed of the vacuum pump **112** may be reduced. When the vacuum pump is at the reduced speed (e.g., baseline pump idle speed), the desired vacuum pressure (e.g., baseline pump idle pressure) in the process chamber **102** may typically be maintained, as no gases a flowing into the process chamber.

**[0033]** At **304**, the pressure within the process chamber **102** may be maintained. For example, a pressure maintainer module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for causing the vacuum pressure to be maintained in the process chamber. The vacuum pump **112** can typically remain in idle (e.g., running at a first pump idle speed equal to the baseline pump idle speed, or some other idle speed less than a predetermined maximum pump idle speed) while the pressure within the process chamber **102** is maintained. However, as shown at **305**, in order to maintain the desired pressure within the process chamber **102**, the first pump idle speed of the vacuum pump **112** must be increased to a second pump idle speed to maintain the desired pressure (e.g., baseline pump idle pressure). For example, if the controller **106** detects from the data provided by the first pressure sensor **104** that the pressure in the process chamber is increasing above a desired setpoint (e.g., baseline pump idle pressure), the controller **106** may send a signal to the pump controller **114** to increase the speed of the vacuum pump **112** in order to maintain the pressure in the process chamber at or near the desired setpoint (e.g., baseline pump idle pressure). The pressure in the process chamber **102** may increase while in idle, for example, due to a leak along the exhaust line, deterioration of the pump, or the like.

**[0034]** At **306**, the second pump idle speed may be compared to the first pump idle speed. For example, an idle speed comparer module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for comparing a pump idle speed with a baseline pump idle speed. In some embodiments, the second pump idle speed may be the current pump speed and the first pump idle speed may be the baseline pump idle speed. For example, the controller **106** may compare the second pump idle speed required to maintain the desired pressure (e.g., baseline pump idle pressure) in the process chamber **102** to the first pump idle speed.

**[0035]** At **308**, it is determined whether the second pump idle speed is comparable to the first pump idle speed. If the second pump idle speed is within a predetermined range or tolerance of the first pump idle speed, the second pump idle speed setpoint may be considered to be comparable to the first pump idle speed and the chamber may continue normal operation, as shown at **310**. However, if the second pump idle speed is outside of a predetermined range or tolerance of the first pump idle speed, or the second pump idle speed exceeds some predetermined maximum pump idle speed, a warning may be generated, as shown at **312**. The warning may be any of the warnings as described above and may be the same warning (or combination of warnings) or may be different warnings in whole or in part. Thus, if the system can maintain the desired pressure (e.g., baseline pump idle pressure) in the process chamber with the vacuum pump **112** running at or below a maximum a predetermined maximum pump idle speed, the chamber may continue normal operations. Otherwise a warning may be generated.

**[0036]** In some embodiments, one or more baseline pump idle speeds may be determined and utilized in the methods described above and further in the methods discussed below. For example, FIG. **4** depicts a method **400** for determining a baseline pump idle speed of a vacuum pump in accordance with some embodiments of the present invention. In some embodiments, the method **400** may be an example of a module of the memory **122** of the controller and may be used to control the processing system as described herein. The method **400** is described below in accordance with the embodiments of the system **100** as shown in FIG. **1**; however, any suitable processing system may be utilized.

**[0037]** The method **400** may be utilized to determine a first baseline pump idle speed of the vacuum pump **112**, where the first baseline pump idle speed may be selected to maintain the process chamber **102** at a first baseline pump idle pressure. For example, the first baseline pump idle pressure may be a pressure of the interior volume **103** of the process chamber **102** and the exhaust line **116**. The first baseline pump idle pressure may be maintained in the system **100** during an idle mode when no gases are flowing and when the valve **108** is open. The method **400** may be performed at startup of the system **100**, after servicing, periodically, or at any desired time when the system **100** is not in a run mode. For example, a first baseline pump idle speed determiner module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for determining the first baseline pump idle speed.

**[0038]** The method **400** begins at **402** by opening the valve **108** separating the process chamber **108** from the exhaust line **116**. The valve **108** may be opened to the maximum setting or to any suitable setting that is used during an idle mode of the system **100**.

**[0039]** At **402**, a pressure in the process chamber **102** equal to the first baseline pump idle pressure while the valve **108** is open. For example, the first baseline pump idle pressure may be measured by the first pressure sensor **104**, the second pressure sensor **110**, or a combination thereof. The initial pump speed of the vacuum pump **112** used to determine the first baseline pump idle pressure may be one or more of the maximum pump speed of the vacuum pump **112** or a maximum pump speed of the vacuum pump **112** that will be used during an idle mode of the system **100**. The initial pump speed may be used to determine the first baseline pump idle pressure. In some embodiments, the first baseline pump idle pressure may be the lowest achievable pressure that may be obtained in the process chamber **102** and the exhaust line **116** while the valve **108** is open.

**[0040]** At **406**, a lowest pump speed of the vacuum pump **112** sufficient to maintain the first baseline pump idle pressure may be determined. The lowest pump speed may be the first baseline pump idle speed. In operation, once the first baseline pump idle pressure is determined, the first baseline pump idle speed may be determined by reducing the pump speed until the pump speed is no longer sufficient to maintain the first baseline pump idle pressure.

**[0041]** FIG. **5** depicts a method **500** for determining a baseline pump idle speed of a vacuum pump in accordance with some embodiments of the present invention. In some embodiments, the method **500** may be an example of a module of the memory **122** of the controller and may be used to control the processing system as described herein. The method **500** is described below in accordance with the embodiments of the system **100** as shown in FIG. **1**; however, any suitable processing system may be utilized. The method **500** may be performed at startup of the system **100**, after servicing, periodically, or at any desired time when the system **100** is not in a production mode. The method **500** may be substantially similar to step **210** of the method **200** as discussed above for determining a baseline pump idle pressure. For example, a second baseline pump idle speed determiner module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for determining the second baseline pump idle speed.

**[0042]** The method **500** begins at **502** by closing the valve **108** to isolate the exhaust line **116** from the process chamber **102**. Accordingly, the baseline pump idle pressure determined by method **500** may be a baseline pump idle pressure of the exhaust line **116**.

**[0043]** At **502**, a pressure of the exhaust line **116** equal to a second baseline pump idle pressure may be determined while the valve **108** is closed. For example, the first baseline pump idle pressure may be measured by the second pressure sensor **110**. The initial pump speed of the vacuum pump **112** used to determine the second baseline pump idle pressure may be one or more of the maximum pump speed of the vacuum pump **112** or a maximum pump speed of the vacuum pump **112** that will be used during an idle mode of the system **100**. The initial pump speed may be used to determine the second baseline pump idle pressure. In some embodiments, the second baseline pump idle pressure may be the lowest achievable pressure that may be obtained in the exhaust line **116** while the valve **108** is closed.

**[0044]** At **506**, a lowest pump speed of the vacuum pump **112** sufficient to maintain the second baseline pump idle pressure may be determined. The lowest pump speed may be the second baseline pump idle speed. In operation, once the

second baseline pump idle pressure is determined, the second baseline idle speed may be determined by reducing the pump speed until the pump speed is no longer sufficient to maintain the second baseline pump idle pressure in the exhaust line **116**.

**[0045]** FIG. **6** depicts a flow chart of a method **600** for controlling a processing system in accordance with some embodiments of the present invention. In some embodiments, the method **600** may be an example of a module of the memory **122** of the controller and may be used to control the processing system as described herein. The method **600** may be substantially similar to the combination of steps **220-234** of method **200** and method **300** as discussed above. Further the method **600** may be utilized after determining the one or more baseline pump idle pressures at methods **400**, **500** and/or step **210** of method **200**.

**[0046]** The method **600** may begin at **602** by operating the vacuum pump **112** at the first baseline pump idle speed selected to maintain the process chamber **102** at a pressure equal to the first baseline pump idle pressure. As discussed above, the first baseline pump idle pressure and first baseline pump idle speed may be determined using method **400**. During operation at **602**, the valve **108** may be open. Further, during operation at **602**, the system **100** may be operating in an idle mode where the vacuum pump is idling and no gases are flowing in the process chamber **102**. For example, vacuum pump operator module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for operating the vacuum pump at a desired pump speed.

**[0047]** At **604**, the pressure in the process chamber may be monitored while operating the vacuum pump at the first baseline pump idle speed. For example, the pressure may be monitored by the first pressure sensor **104**, the second pressure sensor **110**, or a combination thereof. The monitoring of the process chamber may occur while the system **100** is operating in an idle mode, where the vacuum pump **112** is idling and no gases are flowing in the chamber **102**, such from the one or more gas sources **124**. For example, a pressure monitor module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for monitoring the pressure while the vacuum pump is operated at a desired pump speed.

**[0048]** At **606**, a determination may be made as to whether the first baseline pump idle pressure can be maintained in the process chamber **102** while the vacuum pump **112** is operating at the first baseline pump idle speed. For example, the determination at **606** may be made by monitoring the pressure in the process chamber **102** using one or more of the first and second pressure sensors **104**, **110** for a deviation from the first baseline pump idle pressure. The deviation may be predetermined, such as percentage deviation from the first baseline pump idle pressure, or may be determined by measurements during operation, such as a standard deviation from a mean value of pressure measurements while the system **100** operating in an idle mode. For example, a first baseline pump idle pressure determiner module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for determining whether the first baseline pump idle pressure can be maintained in the process chamber.

**[0049]** At **608**, upon monitoring that no deviation in the first baseline pump idle pressure exists, the vacuum pump **112** may continue to operate at the first baseline pump idle speed.

**[0050]** Alternatively, at **610**, upon monitoring that a deviation exists, such as a pressure in the process chamber that is different from the first baseline pump idle pressure, the pump speed of the vacuum pump **112** may be adjusted to a second pump idle speed to maintain the process chamber **102** at the first baseline pump idle pressure. The second pump idle speed may be determined automatically, for example, by a feedback loop between one or more of the first and second pressure sensors **104**, **110** and the pump controller **114** of the vacuum pump **112** upon receiving a signal from the controller **106** when a deviation from the first baseline pump idle pressure has been determined. For example, a first baseline pump idle speed adjuster module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for adjusting the pump idle speed in response to a negative output from the first baseline pump idle pressure determiner module.

**[0051]** At **612**, a determination may be made whether the second pump idle speed is within a predetermined tolerance of the first baseline pump idle speed. For example within a predetermined tolerance may include within the maximum pump speed of the vacuum pump **112** that will be used during an idle mode of the system **100**, within a predetermined range of the first baseline pump idle speed, or other suitable tolerances of the first baseline pump idle speed. For example, second pump idle speed tolerance determiner module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for determining whether the second pump idle speed is within a predetermined tolerance of the first baseline pump idle speed.

**[0052]** At **614**, upon determining that the second pump idle speed is within the predetermined tolerance of the first baseline pump idle speed, the processing system **100** may enter a run mode, such as a production mode or the like. Alternatively, upon determining that the second pump idle speed is within the predetermined tolerance, the system **100** may continue to operate in an idle mode where the vacuum pump **112** may continue to operate at the second baseline pump idle speed. For example, a system run module may be included in the memory **122**, and/or the memory of another controller of the system, to cause or allow the system to operate in a run mode or idle mode in response to a positive output from second pump idle speed tolerance determiner module.

**[0053]** At **616**, upon determining that the second pump idle speed is not within a predetermined tolerance of the first baseline pump idle speed, a system warning may be generated. The system warning may be any suitable system warning as discussed herein. For example, a system warning module may be included in the memory **122** and/or the memory of another controller, such as the pump controller **114** for issuing a system warning in response to a negative output from second pump idle speed tolerance determiner module.

**[0054]** In some embodiments, when a system warning is generated, a diagnostic routine may be run to determine the cause of the system warning. For example, the system may be run in a diagnostic mode where no gases are flowing into the process chamber **102** from the one or more gas sources **124**. Further, the relationship between the second pump idle speed and the second pump idle pressure (as determined by method **500** or step **210** of method **200**) may be utilized to at least narrow the cause of the system warning to a region of the system **100** as discussed below.

**[0055]** The diagnostic mode may include narrowing the source of the system warning to above or below the valve **108**

using the relationship between the second pump idle speed and the second pump idle pressure. For example, the diagnostic mode may begin by closing the valve **108** upon determining that the second pump speed is not within the predetermined tolerance of the first baseline pump idle speed. Next, the vacuum pump **112** may be operated at the second baseline pump idle speed which has been selected to maintain the exhaust line **116** at the second baseline pump idle pressure. The pressure of the exhaust line **116** may be monitored by the second pressure sensor **110** while the vacuum pump **112** is operating at the second baseline pump idle speed. A determination may be made whether the second baseline pump idle pressure can be maintained in the exhaust line **116** when the vacuum pump is operating at the second baseline pump idle speed.

**[0056]** For example, if the pressure of exhaust line **116** remains at the second baseline pump idle pressure while the vacuum pump **112** is operated at the second baseline pump idle speed, it may be determined that the cause of the system warning at **616** may be a component of the system **100** above the valve **108**, such as a leak in the chamber **102** or the like.

**[0057]** Alternatively, upon monitoring a pressure in the exhaust line **116** that is different from the second baseline pump idle pressure, the pump speed of the vacuum pump **112** may be adjusted to a third pump idle speed to maintain the exhaust line **116** at the second baseline pump idle pressure. A determination may be made whether the third pump idle speed is within a predetermined tolerance of the second baseline pump idle speed. The predetermined tolerance may be determined in a similar way to that discussed above at **612**. If the third pump idle speed is within the predetermined tolerance of the second baseline pump idle speed, it may be determined that the cause of the system warning at **616** may be a component of the system **100** above the valve **108**.

**[0058]** If the third pump idle speed is not within the predetermined tolerance of the second baseline pump idle speed, it may be determined that the cause of the system warning at **616** may be a component of the system **100** below the valve **108**, such as a leak in the exhaust line **116** or the like.

**[0059]** Thus, embodiments of the monitoring and control system in accordance with the present invention may provide improved methods of maintaining chamber operating pressure. Additionally, embodiments of the present invention may provide a variety of warnings of impending down time unless preventative maintenance is performed.

**[0060]** Embodiments of the present invention can assure proper chamber operating pressure and additionally can predict need for a down time preventative maintenance check by using an integrated controls solution as described above, chamber and exhaust line pressure readings, the ability to dynamically adjust the vacuum pump idle speed, and the ability to control the position of the valve **108**. In some embodiments, during the controller **106** auto checking procedure for leaks, line clogging, or pump wear out, throttle valve or gate valve position could optionally be managed by the controller **106** to belter differentiate between line clogging and pump wear out root causes.

**[0061]** The following non-limiting examples illustratively depict methods of controlling a process chamber in accordance with some embodiments of the present invention. In some embodiments, the methods of controlling a process chamber as discussed above may be utilized for predictive leak detection. This example is not intended to be the only way to predict a leak using the methods described herein.

**[0062]** Periodically, during non-process chamber recipe cycle time, the controller **106** could perform this test. When the valve **108** is near closed, the pump RPM may be reduced, and a nitrogen purge of the vacuum pump **112** may be set to a fixed flow rate. The pressure at the pump inlet will fall over time and can be compared to an original baseline pressure decay curve. Next, the vacuum pump pressure decay curve over time and variance in the pump pressure decay curve over time may be compared to the baseline pressure decay curve over time and variance in the baseline pressure decay curve over time. Each facilitation, throttle valve, and pump install will produce a unique pressure decay vs. time curve. The baseline curve would need to be determined when equipment or plumbing is reconfigured. Small, medium, and large leaks could be simulated at the time of the base lining via use of a sample port at the gate valve. A statistical analysis can be used to determine the confidence level that will be chosen to send a preventative maintenance warning and provide support data in a pre formatted report.

**[0063]** In some embodiments, the methods of controlling a process chamber as discussed above may be utilized for predictive clog detection. This example is not intended to the only way to track line clogging. Periodically, preferably during non-process chamber recipe cycle time, the controller **106** could perform this test.

**[0064]** When the valve **108** is nearly closed and the chamber pressure rises, with the vacuum pump **112** at high RPM output, the valve **108** may be quickly opened. The pressure rise vs. time curve at the pump and the pressure fall curve vs. time at the chamber may be observed and/or recorded. Comparing the original configuration pump pressure rise over time curve and chamber pressure fall vs. time curve to the post preventative maintenance pressure rise and fall curves will provide data characteristic to the change in Cv value of the exhaust line conductance. The change in Cv value and change in variation in the two key pressure vs. time curves will be indicative of the degree of exhaust line lumen occlusion. Each system can be unique and baseline performance must be characterized for the initial assembly and after pressure transducers, pumps, throttle valves, or chambers have been changed.

**[0065]** In some embodiments, the methods of controlling a process chamber as discussed above may be utilized for pump wear out detection. This example is not intended to the only way to track pump wear out. This issue is very important as new factories use new pumps that are very durable, and subsequently, rebuilt pumps are used until they are so worn out that they are no longer meet minimum reliability threshold specifications.

**[0066]** In some embodiments, with the valve **108** at a preset position, and the pump at maximum or specific high RPM and power output, a significant amount of a low viscosity gas (such as hydrogen or helium) may be flowed into a process chamber **102**. The pump and chamber pressure vs. time may be compared and variation in these curves may be compared to a baseline pump curve capability. As pumps wear, they lose pumping capacity for low viscosity gases in the later compression stages of the pump. This reduced pumping efficiency results a reduction in the pumps ability to maintain a low chamber pressure. Additionally a pump with wear out characteristics experience excess heating of the last few pump compression stages and higher chamber pressures at any given pump RPM. A pump exhibiting wear out characteristics requires more power to maintain the same chamber pressure.

In addition to measuring a increase in chamber pressure, the controller **106** can compare final stage pump temperatures and pump energy requirements for initial commissioning, and monitor pump curves and operational parameters over time. As the pump wears, the system could periodically conduct a pump curve test to determine pump capability. With a statistical evaluation of pump wear out (pump curve and final stage pump temp) over time (with each unique facilitation) the controller **106** can provide a warning that the pump capability is approaching the need for rebuild or change out prior to yield loss and/or significant power waste due to premature pump wear out.

**[0067]** In addition to warnings, the controller **106** can produce standard reports including statistical analysis, change in process capability, and/or confidence level of failure or risk of not performing the recommended preventative maintenance activities.

**[0068]** While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof.

**1**. A method of controlling a processing system, comprising:
operating a vacuum pump coupled to a process chamber at a first baseline pump idle speed selected to maintain the process chamber at a pressure equal to a first baseline pump idle pressure;
monitoring the pressure in the process chamber while operating the vacuum pump at the first baseline pump idle speed; and
determining whether the first baseline pump idle pressure can be maintained in the process chamber when the vacuum pump is operating at the first baseline pump idle speed.

**2**. The method of claim **1**, wherein operating the vacuum pump further comprises operating the vacuum pump at the first baseline pump idle speed when no gases are flowing in the process chamber.

**3**. The method of claim **1**, further comprising:
upon monitoring a pressure in the process chamber that is different from the first baseline pump idle pressure, adjusting the pump speed of the vacuum pump to a second pump idle speed to maintain the process chamber at the first baseline pump idle pressure; and
determining whether the second pump idle speed is within a predetermined tolerance of the first baseline pump idle speed.

**4**. The method of claim **3**, further comprising:
upon determining that the second pump idle speed is within a predetermined tolerance of the first baseline pump idle speed, causing or allowing the processing system to enter a run mode or generating a signal indicating that the processing system can enter the run mode.

**5**. The method of claim **3**, further comprising:
determining the first baseline pump idle speed of the vacuum pump by opening a valve separating the process chamber from an exhaust line coupled to the vacuum pump, determining a pressure in the process chamber equal to the first baseline pump idle pressure while the valve is open, and determining a lowest pump speed of the vacuum pump sufficient to maintain the first baseline pump idle pressure, wherein the lowest pump speed is the first baseline pump idle speed.

**6**. The method of claim **5**, further comprising:
determining a second baseline pump idle speed of the vacuum pump selected to maintain an exhaust line coupling the vacuum pump to the process chamber at a pressure equal to a second baseline pump idle pressure when a valve separating the process chamber and the exhaust line is closed.

**7**. The method of claim **6**, wherein determining the second baseline pump idle speed further comprises:
closing the valve to isolate the exhaust line from the process chamber;
determining a pressure in the exhaust line equal to the second baseline pump idle pressure while the valve is closed; and
determining the lowest pump speed sufficient to maintain the second baseline pump idle pressure, wherein the lowest pump speed is the second baseline pump idle speed.

**8**. The method of claim **6**, further comprising:
upon determining that the second pump idle speed is not within a predetermined tolerance of the first baseline pump idle speed, generating a system warning.

**9**. The method of claim **8**, further comprising:
closing the valve upon determining that the second pump speed is not within a predetermined tolerance of the first baseline pump idle speed;
operating the vacuum pump at the second baseline pump idle speed selected to maintain the exhaust line at the second baseline pump idle pressure;
monitoring the pressure within the exhaust line with the valve closed while no gas is flowing into the process chamber; and
determining whether the second baseline pump idle pressure can be maintained in the exhaust line when the vacuum pump is operating at the second baseline pump idle speed.

**10**. The method of claim **9**, further comprising:
upon monitoring a pressure in the exhaust line that is different from the second baseline pump idle pressure, adjusting the pump speed of the vacuum pump to a third pump idle speed to maintain the exhaust line at the second baseline pump idle pressure; and
determining whether the third pump idle speed is within a predetermined tolerance of the second baseline pump idle speed.

**11**. A computer readable medium having instructions stored thereon that, when executed, cause a method of controlling a processing system to be performed, the method comprising:
operating a vacuum pump coupled to a process chamber at a first baseline pump idle speed selected to maintain the process chamber at a pressure equal to a first baseline pump idle pressure;
monitoring the pressure in the process chamber while operating the vacuum pump at the first baseline pump idle speed; and
determining whether the first baseline pump idle pressure can be maintained in the process chamber when the vacuum pump is operating at the first baseline pump idle speed.

**12**. The computer readable medium of claim **11**, further comprising:
upon monitoring a pressure in the process chamber that is different from the first baseline pump idle pressure,

adjusting the pump speed of the vacuum pump to a second pump idle speed to maintain the process chamber at the first baseline pump idle pressure; and

determining whether the second pump idle speed is within a predetermined tolerance of the first baseline pump idle speed.

**13**. The computer readable medium of claim **12**, further comprising:

upon determining that the second pump idle speed is within a predetermined tolerance of the first baseline pump idle speed, causing or allowing the processing system to enter a run mode or generating a signal indicating that the processing system can enter the run mode.

**14**. The computer readable medium of claim **12**, wherein operating the vacuum pump further comprises operating the vacuum pump at the first baseline pump idle speed when no gases are flowing in the process chamber.

**15**. The computer readable medium of claim **12**, further comprising:

upon determining that the second pump idle speed is not within a predetermined tolerance of the first baseline pump idle speed, generating a system warning.

**16**. A processing system, comprising:

a controller having one or more inputs to receive respective input values corresponding to a pressure in an interior volume of a process chamber and a pump speed of a vacuum pump coupled to the process chamber, wherein the controller is configured to receive the respective input values while the process chamber is in an idle mode, and wherein the controller is further configured to determine whether the process chamber can be maintained at a predetermined pressure corresponding to the vacuum pump operating at or within a predetermined tolerance of a baseline pump idle speed.

**17**. The processing system of claim **16**, wherein the controller is further configured to, upon determining that the process chamber can be maintained at the predetermined pressure corresponding to the vacuum pump operating at or within the predetermined tolerance of the baseline pump idle speed, causing or allowing the processing system to enter a run mode or generating a signal indicating that the processing system can enter the run mode.

**18**. The processing system of claim **16**, wherein the controller is further configured to, upon determining that the process chamber cannot be maintained at the predetermined pressure corresponding to the vacuum pump operating at or within the predetermined tolerance of the baseline pump idle speed, generating a system warning.

**19**. The processing system of claim **18**, wherein the controller is further configured to receive an input value corresponding to a pressure in an exhaust line disposed between the process chamber and the vacuum pump and to determine whether the exhaust line can be maintained at a predetermined pressure corresponding to the vacuum pump operating at or within a predetermined tolerance of a second baseline pump idle speed.

**20**. The processing system of claim **18**, further comprising:

the process chamber having an interior processing volume and the exhaust line coupled to the interior processing volume;

a gas source coupled to the interior processing volume to provide one or more gases to the process chamber;

a valve disposed in the exhaust line;

the vacuum pump coupled to the exhaust line downstream of the valve such that the vacuum pump may be selectively coupled to or isolated from the processing volume via operation of the valve;

a first pressure sensor to provide a first input value of the respective input values corresponding to the pressure within the interior processing volume; and

a second pressure sensor to provide a second input value of the respective input values corresponding to the pressure within the exhaust line between the valve and the vacuum pump.

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