US012386334B2

(12) **United States Patent**
Xu et al.

(10) **Patent No.:** **US 12,386,334 B2**
(45) **Date of Patent:** **Aug. 12, 2025**

(54) **SUSPICIOUS CONTROL VALVE PERFORMANCE DETECTION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 485 days.

(21) Appl. No.: **17/824,152**

(22) Filed: **May 25, 2022**

(65) **Prior Publication Data**

US 2023/0384757 A1 Nov. 30, 2023

(51) **Int. Cl.**
G05B 19/408 (2006.01)
G05B 19/4063 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G05B 19/4063*** (2013.01); ***G05B 19/4065*** (2013.01); ***G05B 19/4083*** (2013.01); ***G05B 23/0221*** (2013.01); *G05B 2219/37333* (2013.01)

(58) **Field of Classification Search**
CPC G05B 19/4063; G05B 19/4065; G05B 19/4083; G05B 2219/37333;
(Continued)

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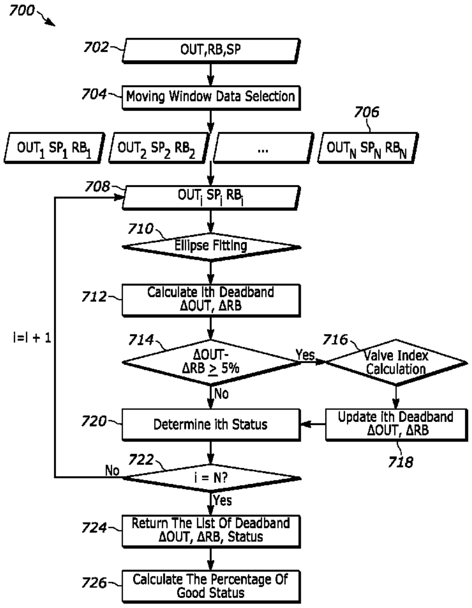
(57) **ABSTRACT**

Techniques for detecting suspicious performance of a throttling control valve (also referred to herein as a "valve") in a process plant are described herein. For each of N time periods, a computing device determines and analyzes process parameter values for process parameters related to a valve to determine a status of the valve for the time period. The computing device compares the valve statuses over the N time periods to determine whether the valve is operating well for at least a threshold portion of at least a subset of the N time periods. In response to determining that the valve is not operating well for at least the threshold portion of at least the subset of the N time periods, the computing device determines that the valve is suspected of performing poorly, and provides an indication of the suspect valve to a user interface for display to a user.

42 Claims, 12 Drawing Sheets



(51) **Int. Cl.**

G05B 19/4065	(2006.01)
G05B 23/02	(2006.01)

(58) **Field of Classification Search**

CPC G05B 23/021; G05B 23/0221; G05B 23/0235; G05B 23/0291; G05B 23/027; G06F 18/22; F16K 37/0041; F16K 37/00; G01M 13/003

See application file for complete search history.

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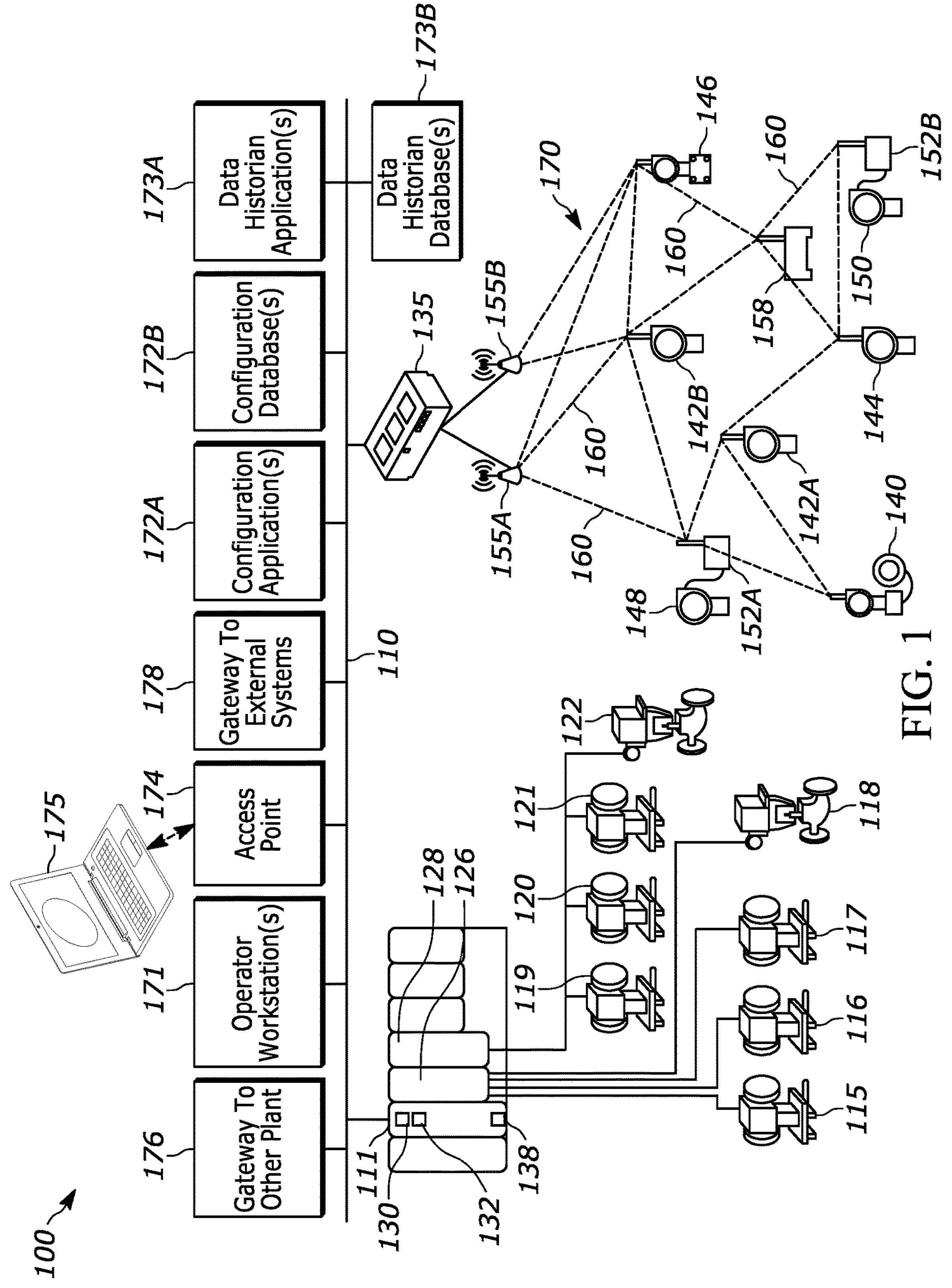
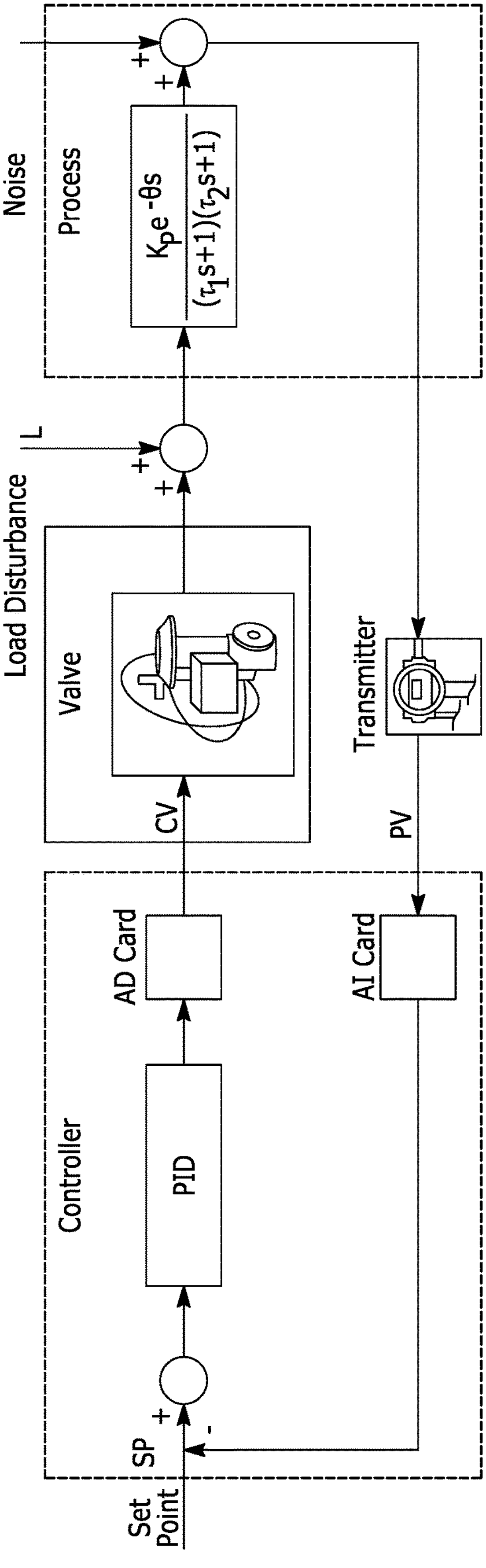

100
176
Gateway To Other Plant
171
Operator Workstation(s)
175
174
Access Point
178
Gateway To External Systems
172A
Configuration Application(s)
172B
Configuration Database(s)
173A
Data Historian Application(s)
173B
Data Historian Database(s)
110
135
155A
155B
170
160
160
160
160
160
146
152B
150
158
142B
144
142A
140
148
152A
111
130
132
138
128
126
119
120
121
122
118
117
116
115

FIG. 1



Prior Art

FIG. 2

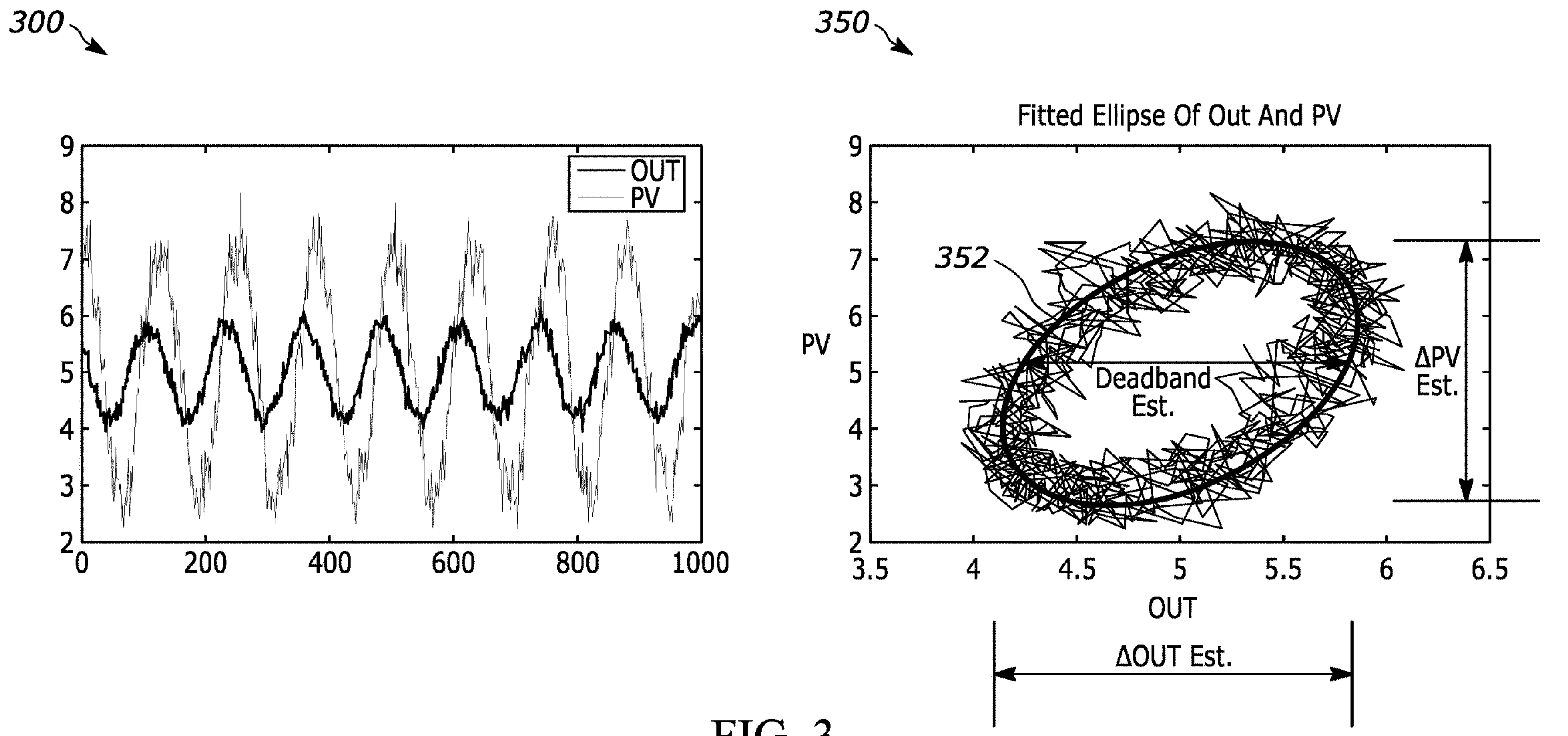

300
350
9
8
7
6
5
4
3
2
0
200
400
600
800
1000
OUT
PV
Fitted Ellipse Of Out And PV
PV
OUT
3.5
4
4.5
5
5.5
6
6.5
352
Deadband
Est.
ΔPV
Est.
ΔOUT Est.

FIG. 3

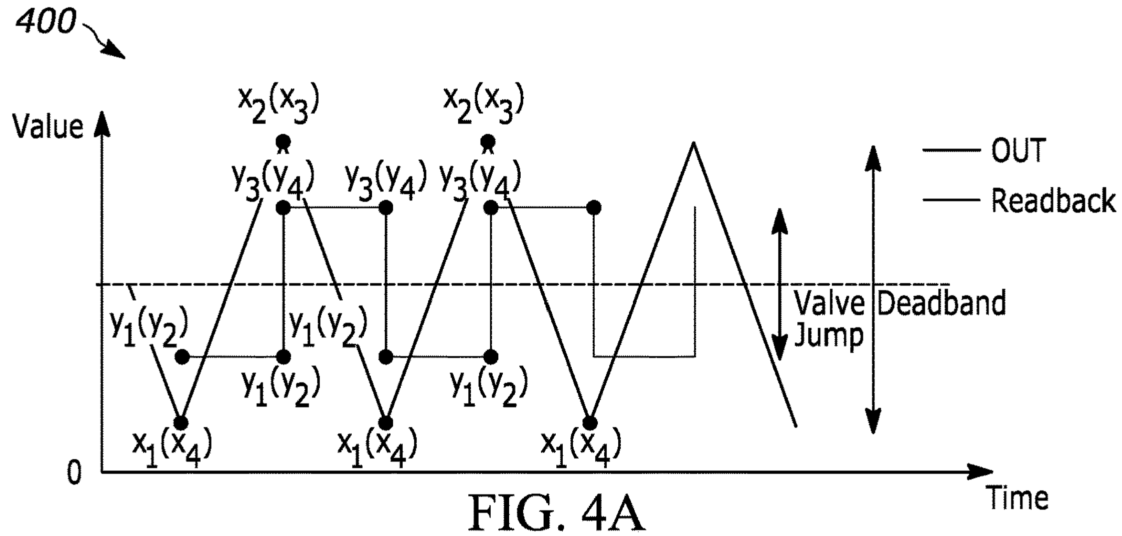


FIG. 4A

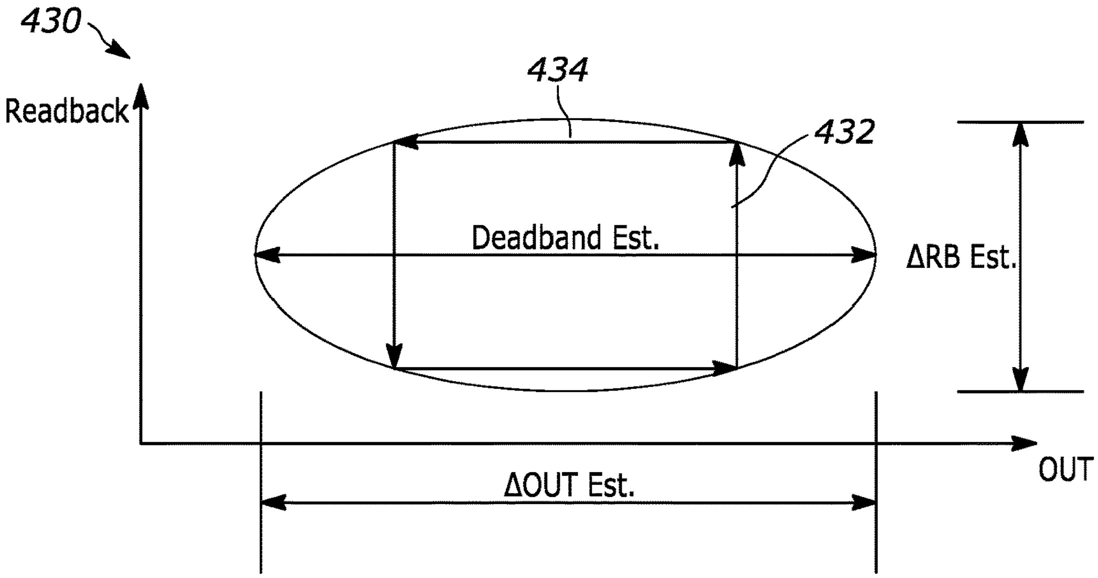


FIG. 4B

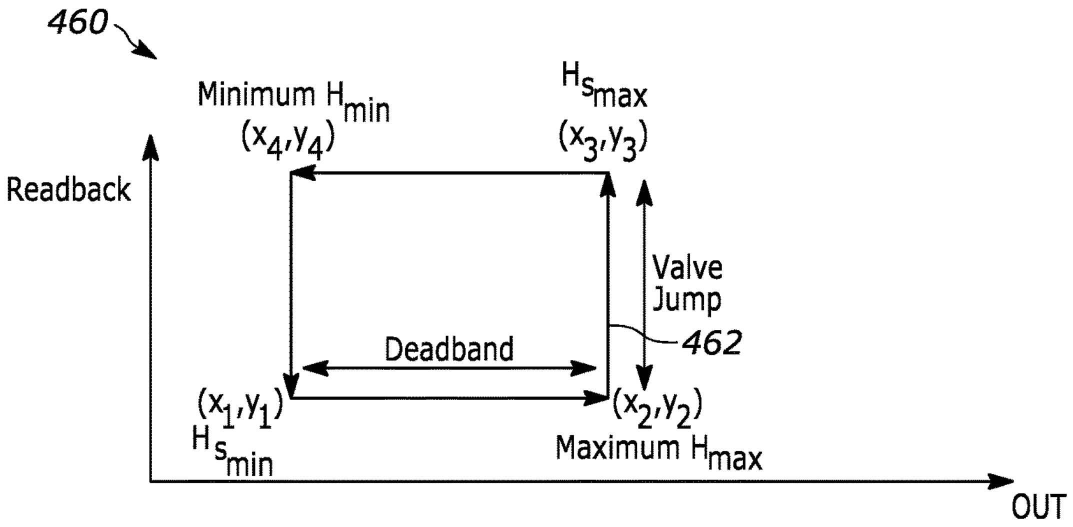


FIG. 4C

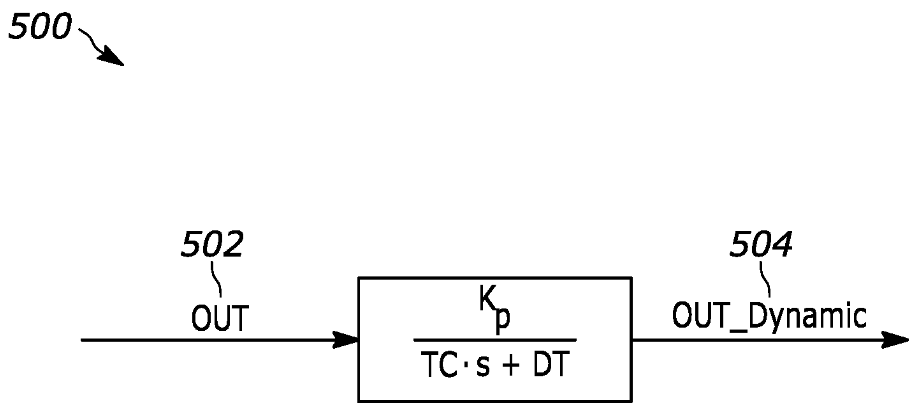
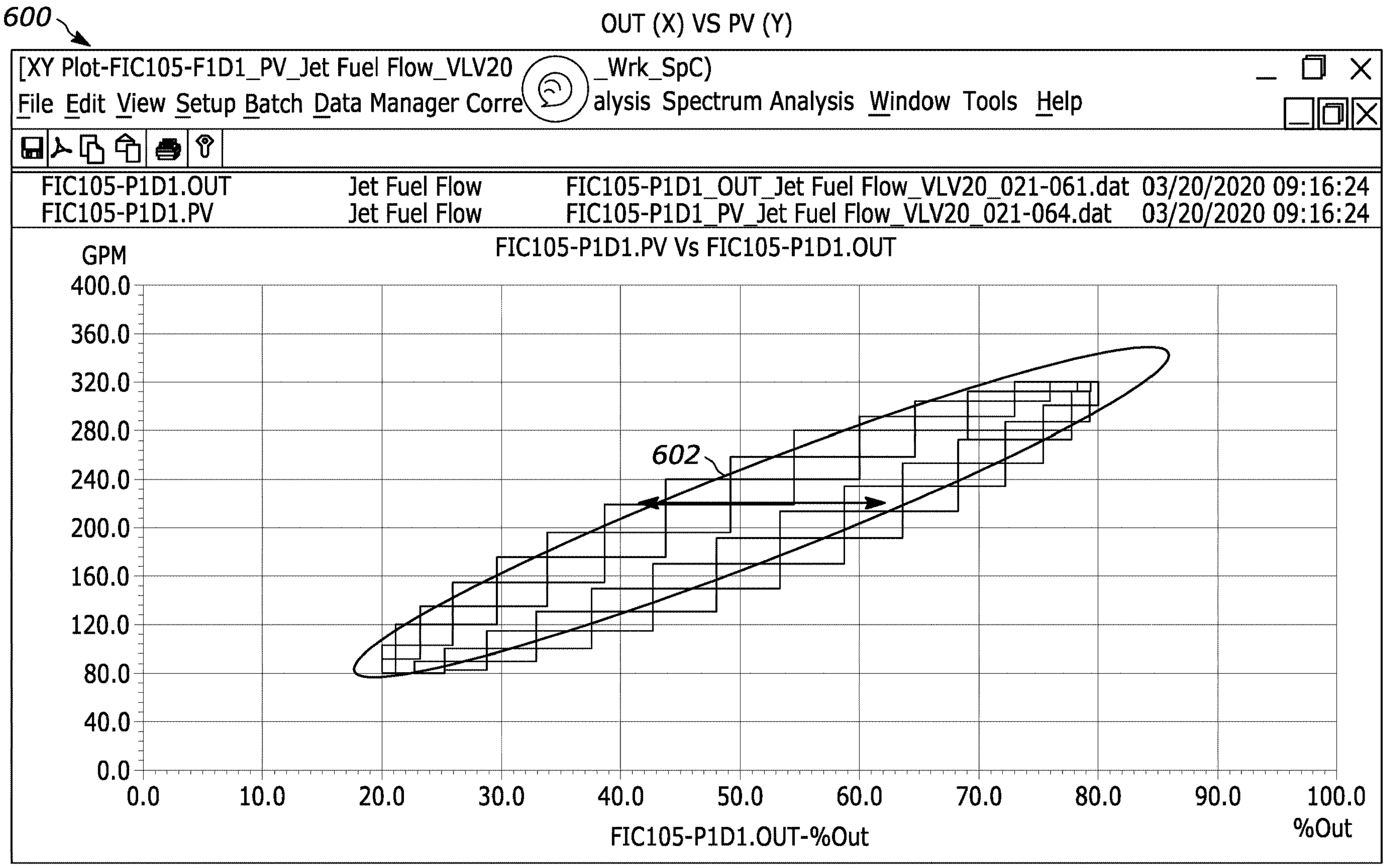
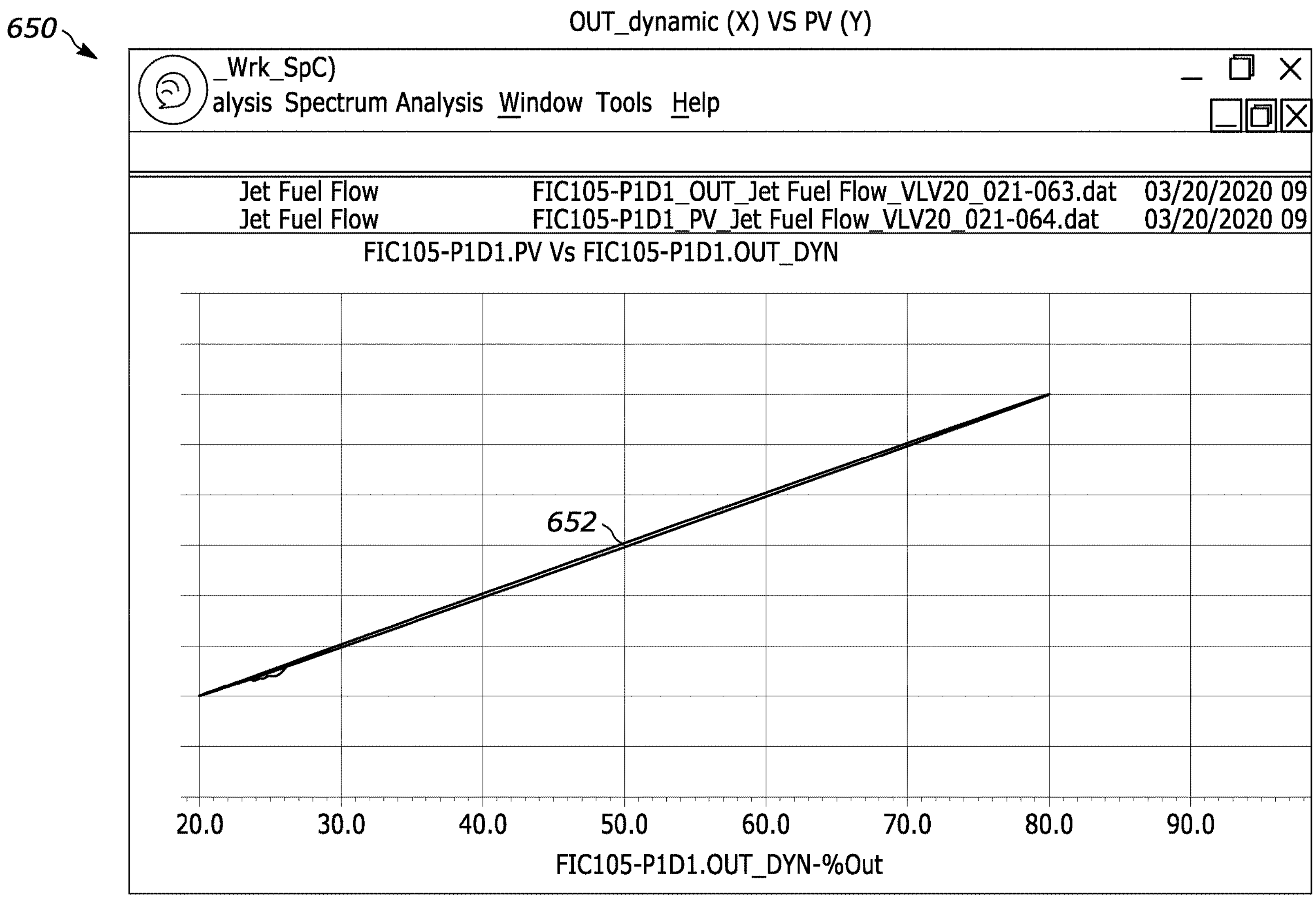


FIG. 5


600
OUT (X) VS PV (Y)
[XY Plot-FIC105-F1D1_PV_Jet Fuel Flow_VLV20 _Wrk_SpC)
File Edit View Setup Batch Data Manager Corre alysis Spectrum Analysis Window Tools Help
FIC105-P1D1.PV Vs FIC105-P1D1.OUT
GPM
400.0
360.0
320.0
280.0
240.0
200.0
160.0
120.0
80.0
40.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
%Out
FIC105-P1D1.OUT-%Out
602
CAP NUM

```
FIC105-P1D1.OUT     Jet Fuel Flow     FIC105-P1D1_OUT_Jet Fuel Flow_VLV20_021-061.dat  03/20/2020 09:16:24
FIC105-P1D1.PV      Jet Fuel Flow     FIC105-P1D1_PV_Jet Fuel Flow_VLV20_021-064.dat   03/20/2020 09:16:24
```

FIG. 6A



```
Jet Fuel Flow     FIC105-P1D1_OUT_Jet Fuel Flow_VLV20_021-063.dat   03/20/2020 09
Jet Fuel Flow     FIC105-P1D1_PV_Jet Fuel Flow_VLV20_021-064.dat    03/20/2020 09
```

FIC105-P1D1.PV Vs FIC105-P1D1.OUT_DYN

FIG. 6B

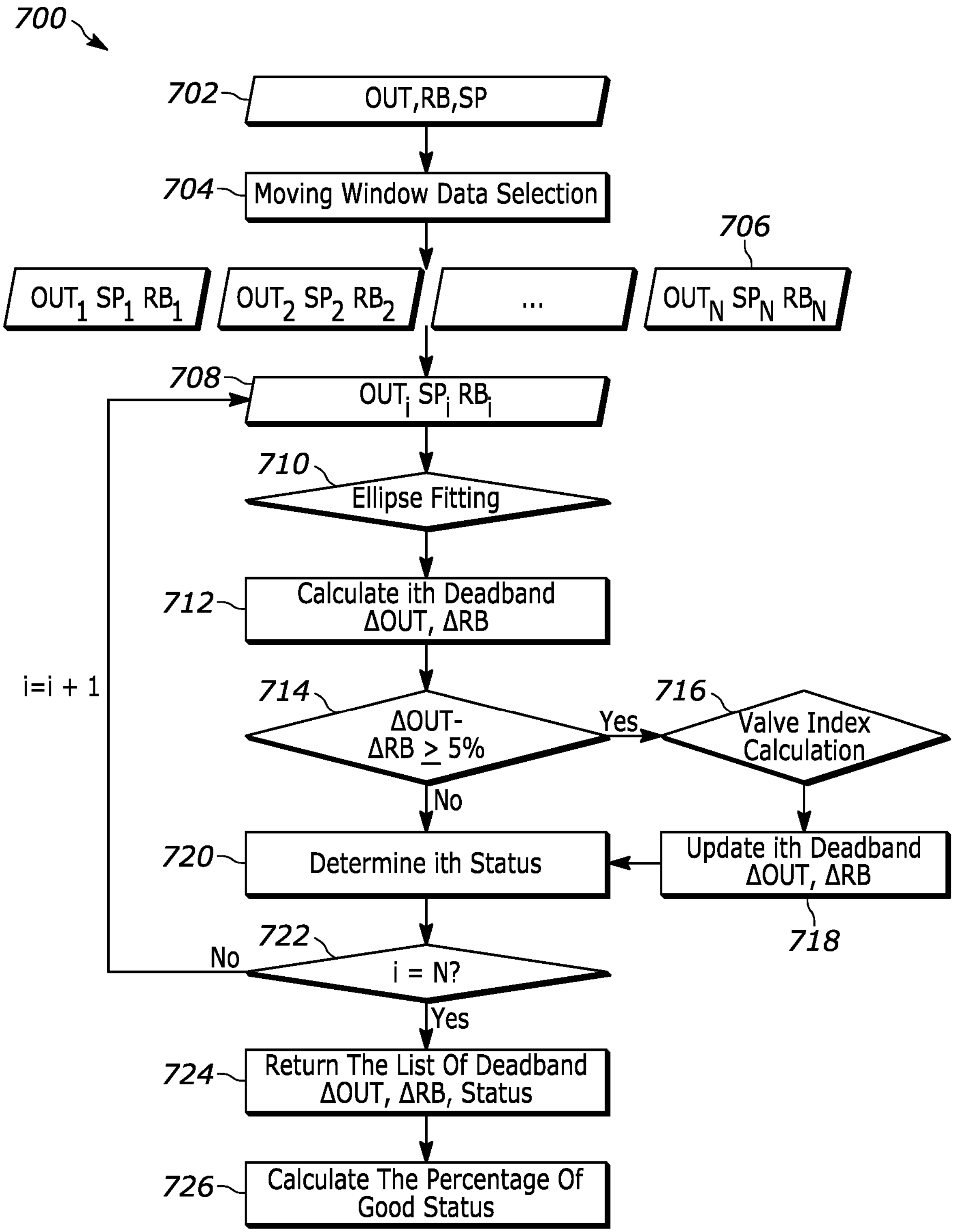

700
702
OUT,RB,SP
704
Moving Window Data Selection
706
OUT1 SP1 RB1
OUT2 SP2 RB2
...
OUTN SPN RBN
708
OUTi SPi RBi
710
Ellipse Fitting
712
Calculate ith Deadband ΔOUT, ΔRB
714
ΔOUT-ΔRB ≥ 5%
Yes
No
716
Valve Index Calculation
718
Update ith Deadband ΔOUT, ΔRB
720
Determine ith Status
722
i = N?
No
Yes
i=i + 1
724
Return The List Of Deadband ΔOUT, ΔRB, Status
726
Calculate The Percentage Of Good Status

FIG. 7

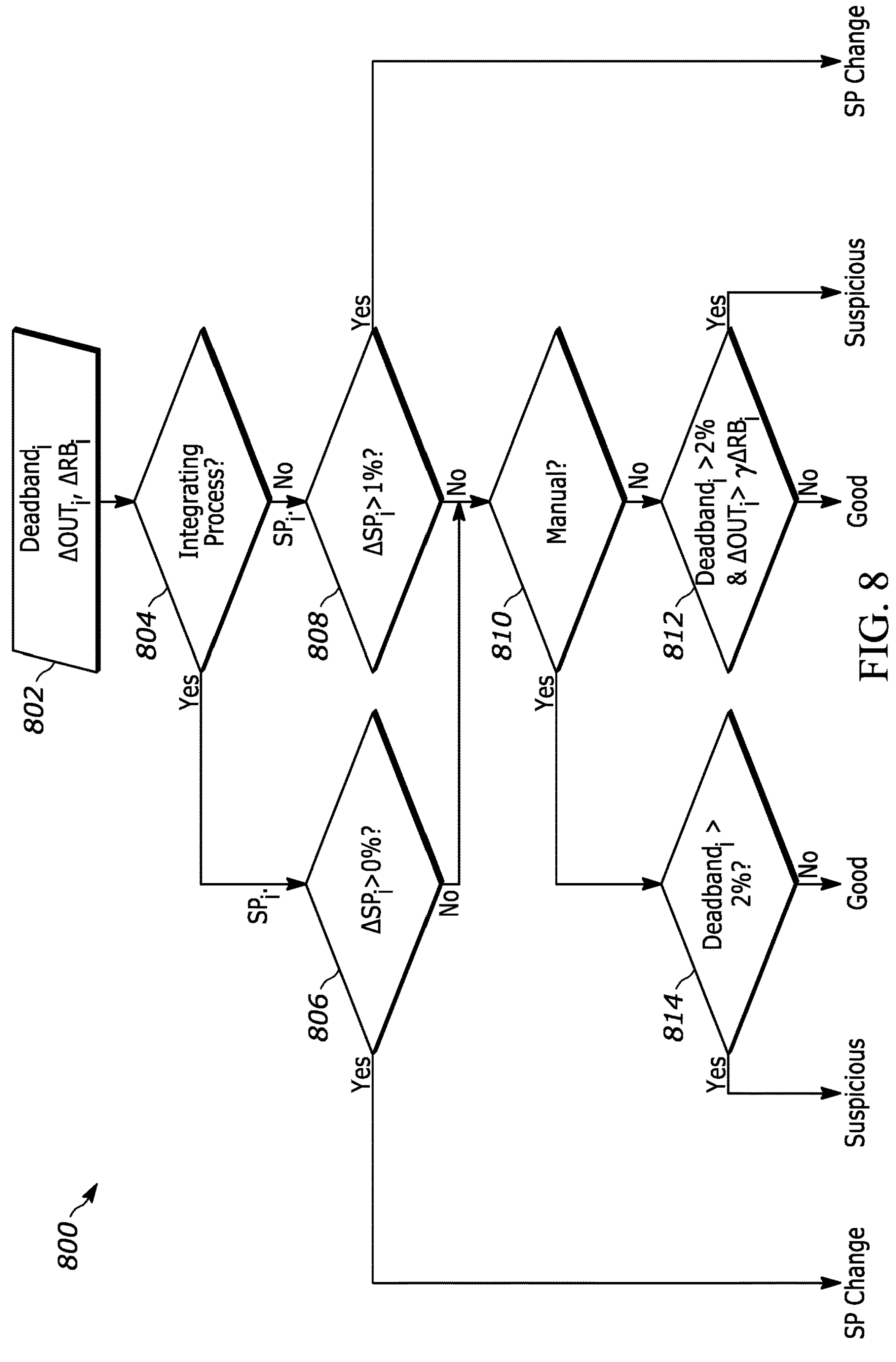

800
802
Deadband_i
ΔOUT_i, ΔRB_i
804
Integrating Process?
Yes
No
SP_i
806
$\Delta\text{SP}_i>0\%$?
Yes
No
SP Change
SP_i
808
$\Delta\text{SP}_i>1\%$?
Yes
No
SP Change
810
Manual?
Yes
No
812
$\text{Deadband}_i>2\%$
& $\Delta\text{OUT}_i>\gamma\Delta\text{RB}_i$
Yes
No
Suspicious
Good
814
$\text{Deadband}_i>$
2%?
Yes
No
Suspicious
Good

FIG. 8

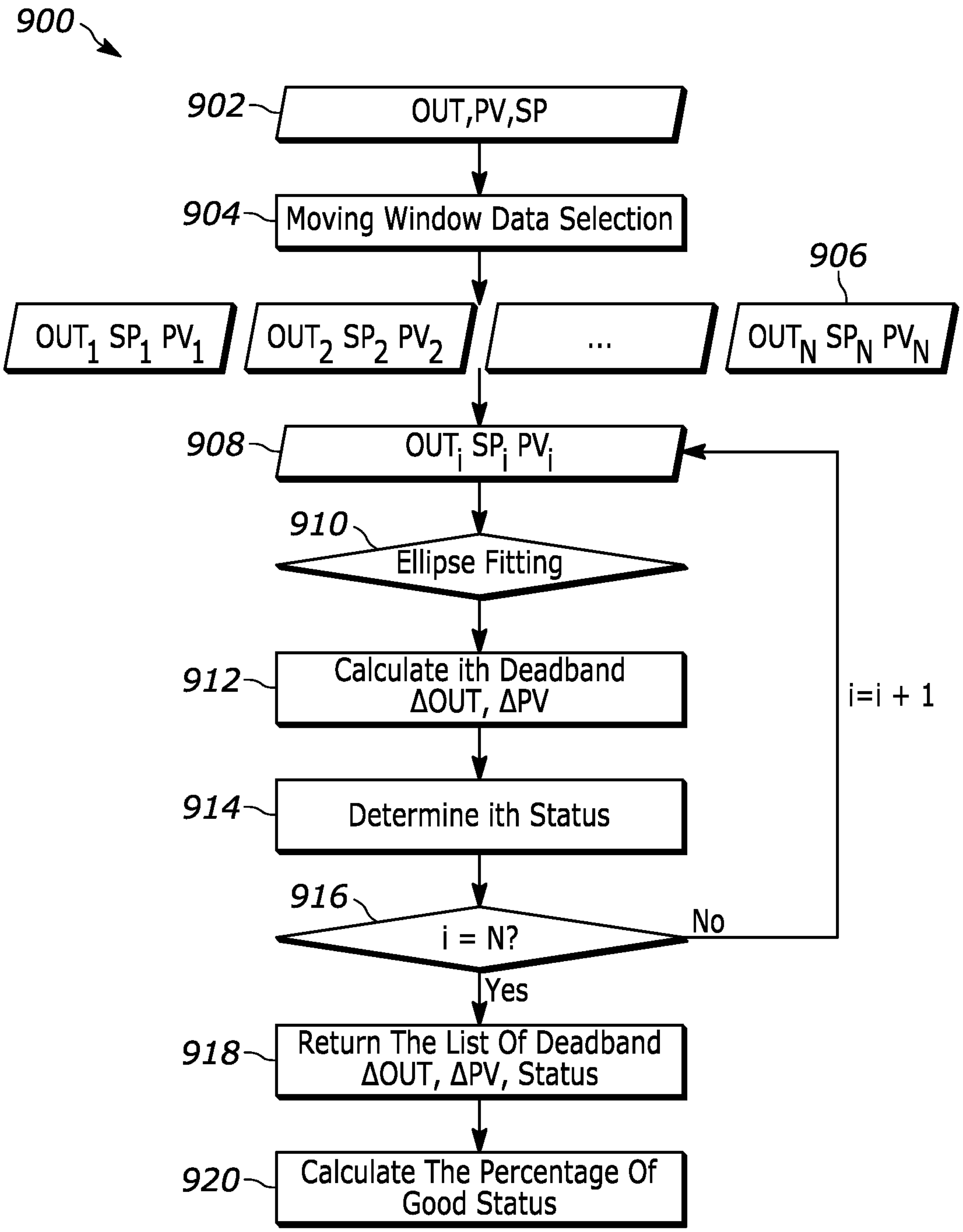

900
902
OUT,PV,SP
904
Moving Window Data Selection
906
OUT$_1$ SP$_1$ PV$_1$
OUT$_2$ SP$_2$ PV$_2$
...
OUT$_N$ SP$_N$ PV$_N$
908
OUT$_i$ SP$_i$ PV$_i$
910
Ellipse Fitting
912
Calculate ith Deadband ΔOUT, ΔPV
914
Determine ith Status
916
i = N?
No
i=i + 1
Yes
918
Return The List Of Deadband ΔOUT, ΔPV, Status
920
Calculate The Percentage Of Good Status

FIG. 9

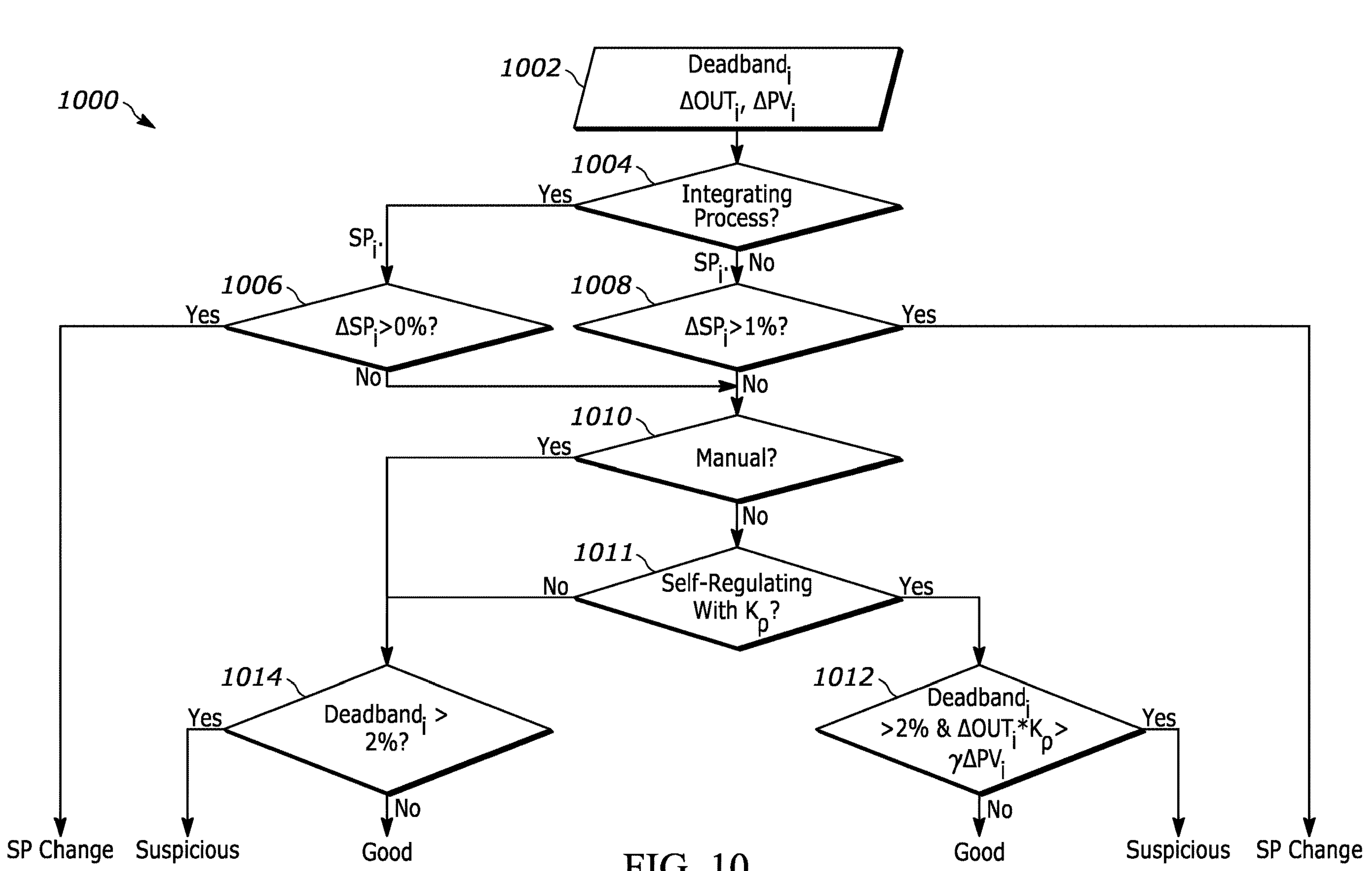
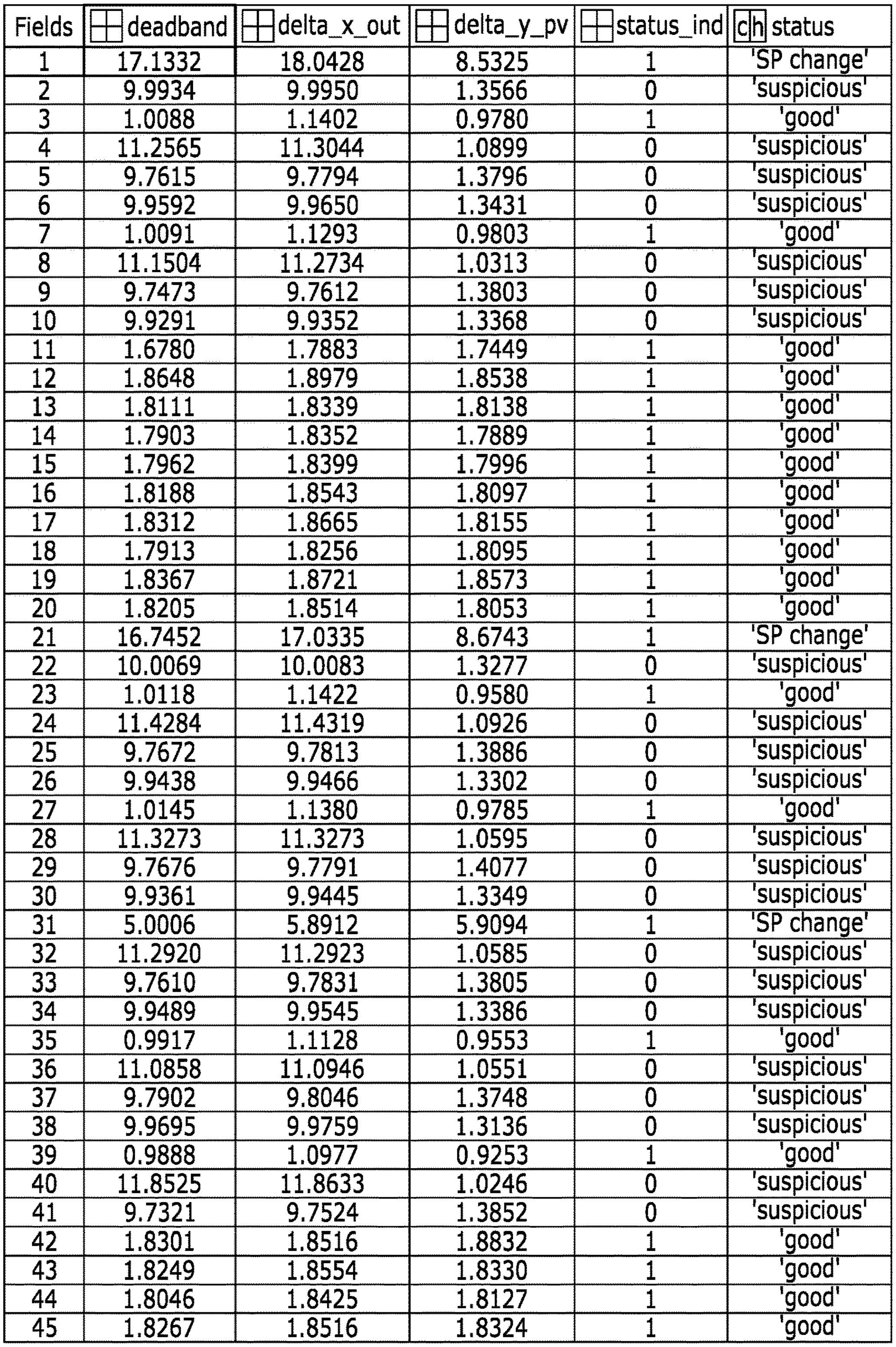

1000
1002
Deadband$_i$
ΔOUT$_i$, ΔPV$_i$
1004
Integrating Process?
Yes
SP$_i$.
No
SP$_i$.
1006
ΔSP$_i$>0%?
Yes
No
1008
ΔSP$_i$>1%?
Yes
No
1010
Manual?
Yes
No
1011
Self-Regulating With K$_p$?
No
Yes
1014
Deadband$_i$ > 2%?
Yes
No
1012
Deadband$_i$ >2% & ΔOUT$_i$*K$_p$> γΔPV$_i$
Yes
No
SP Change
Suspicious
Good
Good
Suspicious
SP Change

FIG. 10



Fields	⊞ deadband	⊞ delta_x_out	⊞ delta_y_pv	⊞ status_ind	ch status
1	17.1332	18.0428	8.5325	1	'SP change'
2	9.9934	9.9950	1.3566	0	'suspicious'
3	1.0088	1.1402	0.9780	1	'good'
4	11.2565	11.3044	1.0899	0	'suspicious'
5	9.7615	9.7794	1.3796	0	'suspicious'
6	9.9592	9.9650	1.3431	0	'suspicious'
7	1.0091	1.1293	0.9803	1	'good'
8	11.1504	11.2734	1.0313	0	'suspicious'
9	9.7473	9.7612	1.3803	0	'suspicious'
10	9.9291	9.9352	1.3368	0	'suspicious'
11	1.6780	1.7883	1.7449	1	'good'
12	1.8648	1.8979	1.8538	1	'good'
13	1.8111	1.8339	1.8138	1	'good'
14	1.7903	1.8352	1.7889	1	'good'
15	1.7962	1.8399	1.7996	1	'good'
16	1.8188	1.8543	1.8097	1	'good'
17	1.8312	1.8665	1.8155	1	'good'
18	1.7913	1.8256	1.8095	1	'good'
19	1.8367	1.8721	1.8573	1	'good'
20	1.8205	1.8514	1.8053	1	'good'
21	16.7452	17.0335	8.6743	1	'SP change'
22	10.0069	10.0083	1.3277	0	'suspicious'
23	1.0118	1.1422	0.9580	1	'good'
24	11.4284	11.4319	1.0926	0	'suspicious'
25	9.7672	9.7813	1.3886	0	'suspicious'
26	9.9438	9.9466	1.3302	0	'suspicious'
27	1.0145	1.1380	0.9785	1	'good'
28	11.3273	11.3273	1.0595	0	'suspicious'
29	9.7676	9.7791	1.4077	0	'suspicious'
30	9.9361	9.9445	1.3349	0	'suspicious'
31	5.0006	5.8912	5.9094	1	'SP change'
32	11.2920	11.2923	1.0585	0	'suspicious'
33	9.7610	9.7831	1.3805	0	'suspicious'
34	9.9489	9.9545	1.3386	0	'suspicious'
35	0.9917	1.1128	0.9553	1	'good'
36	11.0858	11.0946	1.0551	0	'suspicious'
37	9.7902	9.8046	1.3748	0	'suspicious'
38	9.9695	9.9759	1.3136	0	'suspicious'
39	0.9888	1.0977	0.9253	1	'good'
40	11.8525	11.8633	1.0246	0	'suspicious'
41	9.7321	9.7524	1.3852	0	'suspicious'
42	1.8301	1.8516	1.8832	1	'good'
43	1.8249	1.8554	1.8330	1	'good'
44	1.8046	1.8425	1.8127	1	'good'
45	1.8267	1.8516	1.8324	1	'good'

FIG. 11A

$$\text{Good Valve \%} = \frac{20}{45-3} = 47.62\% > 20\%$$

FIG. 11B

SUSPICIOUS CONTROL VALVE PERFORMANCE DETECTION

FIELD OF THE DISCLOSURE

The present disclosure relates to process control systems, and more particularly, to techniques for detecting suspicious performance of a throttling control valve (also referred to herein as a "valve") in a process control system.

BACKGROUND

Distributed process control systems, like those used in chemical, petroleum, pharmaceutical, paper product processing, or other process plants, typically include one or more process controllers communicatively coupled to one or more field devices via analog, digital or combined analog/digital buses, or via a wireless communication link or network. The field devices, which may be, for example, valves, valve positioners, switches and transmitters (e.g., temperature, pressure, level and flow rate sensors), are located within the process environment and generally perform physical or process control functions such as modulating the position of valves, measuring process parameters such as pressure, temperature, etc., and the like to control one or more processes executing within the process plant or system. Smart field devices, such as the field devices conforming to the well-known Fieldbus protocol, may also perform control calculations, alarming functions, and other control functions commonly implemented within the controller. The process controllers, which are also typically located within the plant environment, receive signals indicative of process measurements made by the field devices and/or other information pertaining to the field devices and execute a controller application that runs, for example, different control modules which make process control decisions, generate control signals based on the received information and coordinate with the control modules or blocks being performed in the field devices, such as HART®, WirelessHART®, and FOUNDATION® Fieldbus field devices. The control modules in the controller send the control signals over the communication lines or links to the field devices to thereby control the operation of at least a portion of the process plant or system.

Information from the field devices and the controller is usually made available over a data highway to one or more other hardware devices, such as operator workstations, personal computers or computing devices, data historians, report generators, centralized databases, or other centralized administrative computing devices that are typically placed in control rooms or other locations away from the harsher plant environment. Each of these hardware devices typically is centralized across the process plant or across a portion of the process plant. These hardware devices run applications that may, for example, enable an operator to perform functions with respect to controlling a process and/or operating the process plant, such as changing settings of the process control routine, modifying the operation of the control modules within the controllers or the field devices, viewing the current state of the process, viewing alarms generated by field devices and controllers, simulating the operation of the process for the purpose of training personnel or testing the process control software, keeping and updating a configuration database, etc. The data highway utilized by the hardware devices, controllers and field devices may include a wired communication path, a wireless communication path, or a combination of wired and wireless communication paths.

As an example, the DeltaV™ control system, sold by Emerson Automation Solutions, includes multiple applications stored within and executed by different devices located at diverse places within a process plant. A configuration application, which resides in one or more workstations or computing devices, enables users to create or change process control modules and download these process control modules via a data highway to dedicated distributed controllers. Typically, these control modules are made up of communicatively interconnected function blocks, which are objects in an object-oriented programming protocol that perform functions within the control scheme based on inputs thereto and that provide outputs to other function blocks within the control scheme. The configuration application may also allow a configuration designer to create or change operator interfaces which are used by a viewing application to display data to an operator and to enable the operator to change settings, such as set points, within the process control routines. Each dedicated controller and, in some cases, one or more field devices, stores and executes a respective controller application that runs the control modules assigned and downloaded thereto to implement actual process control functionality. The viewing applications, which may be executed on one or more operator workstations (or on one or more remote computing devices in communicative connection with the operator workstations and the data highway), receive data from the controller application via the data highway and display this data to process control system designers, operators, or users using the user interfaces, and may provide any of a number of different views, such as an operator's view, an engineer's view, a technician's view, etc. A data historian application is typically stored in and executed by a data historian device that collects and stores some or all of the data provided across the data highway while a configuration database application may run in a still further computer attached to the data highway to store the current process control routine configuration and data associated therewith. Alternatively, the configuration database may be located in the same workstation as the configuration application.

For example, process plants use valves in a wide variety of applications from controlling process flow in petroleum refineries to maintaining fluid levels in tank farms. Valves, which are typically automated, are used to manage such fluid flow or pressure drop by functioning like a variable orifice or passage. By controlling the position of an internal valve component, such as a valve plug, the amount of product passing through, or the differential pressure created by the valve body can be accurately regulated. A typical proportional-integral-derivative (PID) control loop is illustrated in FIG. **2**. As shown in FIG. **2**, in the PID control loop, a controller has a set point value and generates and transmits a controller output (OUT) to a control valve that changes the process in a way that causes the process variable (PV) to achieve the value of the set point. The valve opens or closes in accordance with the controller output and the process parameter value is adjusted in accordance with the travel of the valve. Then the adjusted process parameter value is fed back to the controller, via a transmitter, and the controller continues to adjust the output accordingly.

In some scenarios, the valve may not respond properly to the control output signal due to dead band, resolution, lost motion, internal friction, variable flow gain, variable response time, etc. This may result in performance degradation leading to inferior products, increased energy consumption, lower production capacity, etc. As a result, in some process control systems, the performance statuses (also referred to herein as "statuses") of control valves are monitored to ensure consistency, economy, and safety in the process plant. However, typical valve monitoring systems are inaccurate and generate too many false alarms.

SUMMARY

Referring to FIG. **2**, note that changes in the load, L, on the process can change the relationship between the process parameters and the valve position which can cause a false indication of poor valve performance. To accurately detect valves suspected of performing poorly in a process plant, a computing device such as an operator workstation or portable user interface device uses a moving time window to analyze the valve performance over N windows or time periods. For example, each of the N windows may have a period of 30 minutes and N may be 10 windows. In this scenario, the process may last 5 hours. For each time period, the computing device analyzes process parameter values for process parameters related to the valve to determine the status of the valve for the particular time period. In some implementations, the valve status may be good, suspect, or another status indicating that the valve status should be ignored for the time period, such as a set point change. Then the computing device detects a valve suspected of performing poorly (also referred to herein as a "suspect valve") when the valve performs as required for less than a threshold portion of the N time periods (e.g., 20%), or less than a threshold portion of a subset of the N time periods where the valve status is not ignored.

By using a moving time window and detecting a suspect valve using several valve statuses over N time periods, the number of false detections or the false alarm rate may be significantly reduced. While valves operating well may occasionally perform poorly over a few time periods, the computing device will detect good operation more frequently over the moving time window than for a valve suspected of performing poorly. Accordingly, the moving time window allows for the computing device to more accurately distinguish between a valve operating well and a valve performing below requirements.

Furthermore, the computing device determines the valve status during a particular time period based on process parameter values during the time period for process parameters related to the valve. The process parameters may include the valve travel, the controller output, the set point (SP), the process gain, or a process variable (PV) for a process plant entity coupled to the valve. For example, the process plant entity may be a tank and the process variable may be the tank fill level, the tank fill volume, a fluid pressure, or a fluid flow rate.

In some implementations, a valve travel sensor obtains valve travel values for the valve and provides the valve travel values to the computing device. In these implementations, the computing device determines the valve status at a particular time period by using the controller output values over the time period and the valve travel values over the time period to estimate performance metrics for the valve, such as the change in the controller output, the change in valve travel, and/or the dead band over the time period. The dead band may be the range through which an input signal may be varied, with reversal of direction, without initiating an observable change in the output signal. The dead band may be a percentage of the input span. The resolution may be the smallest step increment of an input signal in one direction in which movement of the output is observed. The resolution may also be a percentage of the input span.

The computing device may estimate the change in the controller output, the change in valve travel, and/or the dead band over the time period using an ellipse fitting algorithm. For example, the computing device may plot a graph of the valve travel values as a function of the controller output values, fit an ellipse to the values, and use characteristics of the ellipse to estimate the change in the controller output, the change in valve travel, and/or the dead band over the time period. In other implementations, the computing device may estimate the change in the controller output, the change in valve travel, and/or the dead band over the time period using a valve index calculation. For example, the computing device may plot a graph of the valve travel values as a function of the controller output values, and use the graph vertices to estimate the change in the controller output, the change in valve travel, and/or the dead band over the time period.

Then the computing device may determine the valve status for the time period based on the performance metrics, such as the estimated change in the controller output, the estimated change in valve travel, and/or the estimated dead band over the time period. For example, when the dead band for the time period exceeds a threshold dead band percentage, the computing device may determine that the valve status for the time period is suspect. When the dead band for the time period does not exceed the threshold dead band percentage, the computing device may determine that the valve status for the time period is good. In another example, when the change in the controller output is greater than the change in valve travel for the time period or greater than the change in valve travel multiplied by a predetermined constant (γ), the computing device may determine that the valve status for the time period is suspect. When the change in the controller output is not greater than the change in valve travel for the time period or not greater than the change in valve travel multiplied by the predetermined constant (γ), the computing device may determine that the valve status for the time period is good. More generally, the computing device may detect that the valve is operating well when the valve responds properly to control output signals in accordance with the performance metrics. The computing device may detect that the valve is suspected of performing poorly when the valve does not respond properly to control output signals in accordance with the performance metrics.

In other implementations, valve travel data is unavailable or inaccessible. For example, the valve is not communicatively coupled to a valve travel sensor. In these implementations, the computing device determines the valve status at a particular time period by using the controller output values over the time period and the process variable values over the time period to estimate the change in the controller output, the change in the process variable, and/or the dead band over the time period. The computing device may estimate the change in the controller output, the change in the process variable, and/or the dead band over the time period using an ellipse fitting algorithm. For example, the computing device may plot a graph of the process variables values as a function of the controller output values, fit an ellipse to the values, and use characteristics of the ellipse to estimate the change in the controller output, the change in the process variable, and/or the dead band over the time period.

Then the computing device may determine the valve status for the time period based on the estimated change in the controller output, the estimated change in the process variable, and/or the estimated dead band over the time period. For example, when the dead band for the time period exceeds a threshold dead band percentage, the computing device may determine that the valve status for the time period is suspect. When the dead band for the time period does not exceed the threshold dead band percentage, the computing device may determine that the valve status for the time period is good. In another example, when a product of the change in the controller output and the process gain is greater than the change in the process variable for the time period or greater than the change in the process variable multiplied by the predetermined constant (γ), the computing device may determine that the valve status for the time period is suspect. When the product of the change in the controller output and the process gain is not greater than the change in the process variable for the time period or not greater than the change in the process variable multiplied by the predetermined constant (γ), the computing device may determine that the valve status for the time period is good.

Also in some implementations, the controller output values are dynamic controller output values. The computing device may determine the dynamic controller output value based on the controller output value, the process gain, a time constant (TC), and a dead time (DT). Then the computing device determines the dead band, the change in the controller output, and the change in valve travel or the process variable using the dynamic controller output values. By using dynamic controller output values the accuracy of the estimation of the dead band is improved by reducing the nonlinearity between the output and the PV and/or reducing noise.

In one implementation, a method detects a suspect valve in a process plant. For each of N time periods, the method includes determining one or more process parameter values for one or more process parameters related to a valve during the time period, and analyzing the one or more process parameter values to determine a status of the valve for the time period. The method also includes comparing the valve statuses over the N time periods to determine whether the valve is operating well for at least a threshold portion of at least a subset of the N time periods. In response to determining that the valve is not operating well for at least the threshold portion of at least the subset of the N time periods, the method includes determining that the valve is a suspect valve, and providing an indication of the suspect valve to a user interface for display to a user, such as an operator, an engineer, an instrument technician, a maintenance person, or some other process plant personnel. The indication may be provided as a status, an alert, or a notification.

In another implementation, a computing device for detecting a suspect valve in a process plant includes one or more processors, and a non-transitory computer-readable memory coupled to the one or more processors and storing instructions thereon. The instructions when executed by the one or more processors, cause the computing device to for each of N time periods, determine one or more process parameter values for one or more process parameters related to a valve during the period, and analyze the one or more process parameter values to determine a status of the valve for the time period. The instructions further cause the computing device to compare the valve statuses over the N time periods to determine whether the value is operating well for at least a threshold portion of at least a subset of the N time periods. In response to determining that the valve is not operating well for at least the threshold portion of at least the subset of the N time periods, the instructions cause the computing device to determine that the valve is a suspect valve, and

provide an indication of the suspect valve to a user interface for display to a user, such as an operator, an engineer, an instrument technician, a maintenance person, or some other process plant personnel. The indication may be provided as a status, an alert, or a notification.

In yet another implementation, a process control system includes a controller configured to control a valve, the valve configured to control operation of a process plant entity executing within a process plant, and a computing device. The computing device includes one or more processors, and a non-transitory computer-readable memory coupled to the one or more processors and storing instructions thereon. The instructions when executed by the one or more processors, cause the computing device for each of N time periods, to determine one or more process parameter values for one or more process parameters related to the valve during the time period, the one or more process parameters including at least one of: an output from the controller, a valve travel, a process variable for the process plant entity, a process gain between the process variable and the controller output, or a dead band, and analyze the one or more process parameter values to determine a status of the valve for the time period. The instructions further cause the computing device to compare the valve statuses over the N time periods to determine whether the value is operating well for at least a threshold portion of at least a subset of the N time periods. In response to determining that the valve is not operating well for at least the threshold portion of at least the subset of the N time periods, the instructions cause the computing device to determine that the valve is a suspect valve, and provide an indication of the suspect valve to a user interface for display to user, such as an operator, an engineer, an instrument technician, a maintenance person, or some other process plant personnel. The indication may be provided as a status, an alert, or a notification.

In another implementation, a method reduces false alarm rates in suspect valve detection using a moving time window. The method includes determining a status of a valve in a process plant for each of N time periods, determining a proportion of at least a subset of the N time periods in which the valve status indicates the valve is operating well, and providing an indication that the valve is a suspect valve to a user interface for display to a user in response to determining that the proportion is less than a threshold proportion.

In yet another implementation, a method detects a suspect valve in a process plant. The method includes determining one or more dynamic process parameter values for one or more dynamic process parameters related to a valve. The one or more dynamic process parameters include a dynamic controller output determined based on at least one of a time constant, a process gain, or a dead time. The method further includes analyzing the one or more dynamic process parameter values to determine a status of the valve, and providing an indication that the valve is a suspect valve in accordance with the status of the valve to a user interface for display to a user, such as an operator, an engineer, an instrument technician, a maintenance person, or some other process plant personnel. The indication may be provided as a status, an alert, or a notification

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of an example process plant that illustrates, inter alia, interconnections between various example components of the process plant or process control system, the process control system itself, and other example systems and/or networks;

FIG. **2** is a block diagram of an example control loop including a controller, a valve, and a process plant entity coupled to the valve;

FIG. **3** illustrates example graphs of controller output values and process variable values as a function of time, and the process variable values as a function of the controller output values;

FIGS. **4**A-**4**C illustrate illustrates example graphs of controller output values and valve travel values as a function of time, and the valve travel values as a function of the controller output values;

FIG. **5** illustrates an example block diagram of the relationship between controller output values and dynamic controller output values which are determined using process dynamics;

FIGS. **6**A-**6**B illustrates an example comparison of a dead band estimation using an ellipse fitting algorithm by plotting a first graph of process variable values as a function of controller output values and plotting a second graph of process variable values as a function of dynamic controller output values;

FIG. **7** is a flow diagram of an example method for detecting a suspect valve in a process plant using a moving time window when valve travel data is available, which may be implemented by a computing device such as an operator workstation;

FIG. **8** is a flow diagram of a detailed method of the method of FIG. **7** for determining the status of the valve for a particular time period of N time periods;

FIG. **9** is a flow diagram of an example method for detecting a suspect valve in a process plant using a moving time window when valve travel data is unavailable, which may be implemented by a computing device such as an operator workstation;

FIG. **10** is a flow diagram of a detailed method of the method of FIG. **9** for determining the status of the valve for a particular time period of N time periods; and

FIGS. **11**A-**11**B illustrate example results of the suspect valve analysis including the valve status for each of the N time periods and a comparison of the valve statuses over the N time periods to a threshold portion of at least a subset of the N time periods to determine whether the valve is a suspect valve.

DETAILED DESCRIPTION

FIG. **1** is a block diagram of an example process plant **100** which is configured to control an industrial process during on-line or run-time operations. The process plant **100** (which is also interchangeably referred to herein as a process control system **100** or process control environment **100**) includes one or more process controllers that receive signals indicative of process and/or other types of measurements made by field devices, process this information to implement a control routine, and generate control signals that are sent over wired or wireless process control communication links or networks to other field devices to control the operation of an industrial process in the plant **100**. Typically, at least one field device performs a physical function (e.g., opening or closing a valve, increasing or decreasing a temperature, taking a measurement, sensing a condition, etc.) to control the operation of the process. Some types of field devices communicate with controllers by using I/O devices. Process controllers, field devices, and I/O devices may be wired or wireless, and any number and combination of wired and wireless process controllers, field devices and I/O devices may be included in the process plant environment or system **100**.

For example, FIG. **1** illustrates a process controller **111** that is communicatively connected to wired field devices **115**-**122** via input/output (I/O) cards **126** and **128**, and that is communicatively connected to wireless field devices **140**-**146** via a wireless gateway **135** and a process control data highway or backbone **110**. The process control data highway **110** may include one or more wired and/or wireless communication links, and may be implemented using any desired or suitable or communication protocol such as, for example, an Ethernet protocol, an IP or other packet protocol, etc. In some configurations (not shown), the controller **111** may be communicatively connected to the wireless gateway **135** using one or more communications networks other than or in addition to the backbone **110**, such as by using any number of other wired or wireless communication links that support one or more communication protocols, data protocols, and/or industrial automation protocols, e.g., Wi-Fi or other IEEE 802.11 compliant wireless local area network protocol, mobile communication protocol (e.g., WiMAX, LTE, or other ITU-R compatible protocol), Bluetooth®, HART®, WirelessHART®, HART-IP, Profibus, FOUNDATION® Fieldbus, etc.

The controller **111**, which may be, by way of example, the DeltaV™ controller sold by Emerson Process Management, may operate to implement a batch process or a continuous process using at least some of the field devices **115**-**122** and **140**-**146**. In an embodiment, in addition to being communicatively connected to the process control data highway **110**, the controller **111** is also communicatively connected to at least some of the field devices **115**-**122** and **140**-**146** using any desired hardware and software associated with, for example, standard 4-20 mA devices, I/O cards **126**, **128**, and/or any smart communication protocol such as the FOUNDATION® Fieldbus protocol, the HART® protocol, the WirelessHART® protocol, etc. In FIG. **1**, the controller **111**, the field devices **115**-**122** and the I/O cards **126**, **128** are wired devices, and the field devices **140**-**146** are wireless field devices. Of course, the wired field devices **115**-**122** and wireless field devices **140**-**146** could conform to any other desired standard(s) or protocols, such as any wired or wireless protocols, including any standards or protocols developed in the future.

The process controller **111** of FIG. **1** includes a processor **130** that implements or oversees one or more process control routines **138** (e.g., that are stored in a memory **132**). The processor **130** is configured to communicate with the field devices **115**-**122** and **140**-**146** and with other nodes that are communicatively connected to the controller **111**. It should be noted that any control routines or modules described herein may have parts thereof implemented or executed by different controllers or other devices if so desired. Likewise, the control routines or modules **138** described herein which are to be implemented within the process control system **100** may take any form, including software, firmware, hardware, etc. Control routines may be implemented in any desired software format, such as using object-oriented programming, ladder logic, sequential function charts, function block diagrams, or using any other software programming language or design paradigm. The control routines **138** may be stored in any desired type of memory **132**, such as random access memory (RAM), or read only memory (ROM). Likewise, the control routines **138** may be hard-coded into, for example, one or more EPROMs, EEPROMs, application specific integrated circuits (ASICs), or any other hardware or firmware elements. Thus, the controller **111** may be configured to implement a control strategy or control routine in any desired manner.

The controller **111** implements a control strategy using what are commonly referred to as function blocks, where each function block is an object or other part (e.g., a subroutine) of an overall control routine and operates in conjunction with other function blocks (via communications called links) to implement process control loops within the process control system **100**. Control based function blocks typically perform one of an input function, such as that associated with a transmitter, a sensor or other process parameter measurement device; a control function, such as that associated with a control routine that performs PID, fuzzy logic, etc. control; or an output function which controls the operation of some device, such as a valve, to perform some physical function within the process control system **100**. Of course, hybrid and other types of function blocks exist. Function blocks may be stored in and executed by the controller **111**, which is typically the case when these function blocks are used for control, are associated with standard 4-20 mA devices and some types of smart field devices such as HART® devices or Profibus devices, or may be stored in and implemented by the field devices or IO cards themselves, which can be the case with FOUNDATION® Fieldbus devices. The controller **111** may include one or more control routines **138** that may implement one or more control loops which are performed by executing one or more of the function blocks.

The wired field devices **115-122** may be any types of devices, such as sensors, valves, transmitters, positioners, etc., while the I/O cards **126** and **128** may be any types of I/O devices conforming to any desired communication or controller protocol. In FIG. **1**, the field devices **115-118** are standard 4-20 mA devices or HART® devices that communicate over analog lines or combined analog and digital lines to the I/O card **126**, while the field devices **119-122** are smart devices, such as FOUNDATION® Fieldbus field devices, that communicate over a digital bus to the I/O card **128** using a FOUNDATION® Fieldbus communications protocol. In some embodiments, though, at least some of the wired field devices **115**, **116** and **118-121** and/or at least some of the I/O cards **126**, **128** additionally or alternatively communicate with the controller **111** using the process control data highway **110** and/or by using other suitable control system protocols (e.g., Profibus, DeviceNet, Foundation Fieldbus, ControlNet, Modbus, HART, etc.).

In FIG. **1**, the wireless field devices **140-146** communicate via a wireless process control communication network **170** using a wireless protocol, such as the WirelessHART® protocol. Such wireless field devices **140-146** may directly communicate with one or more other devices or nodes of the wireless network **170** that are also configured to communicate wirelessly (using the wireless protocol or another wireless protocol, for example). To communicate with other nodes that are not configured to communicate wirelessly, the wireless field devices **140-146** may utilize a wireless gateway **135** connected to the process control data highway **110** or to another process control communications network. The wireless gateway **135** provides access to various wireless devices **140-158** of the wireless communications network **170**. In particular, the wireless gateway **135** provides communicative coupling between the wireless devices **140-158**, the wired devices **115-128**, and/or other nodes or devices of the process control plant **100**. For example, the wireless gateway **135** may provide communicative coupling by using the process control data highway **110** and/or by using one or more other communications networks of the process plant **100**.

Similar to the wired field devices **115-122**, the wireless field devices **140-146** of the wireless network **170** perform physical control functions within the process plant **100**, e.g., opening or closing valves, or taking measurements of process parameters. The wireless field devices **140-146**, however, are configured to communicate using the wireless protocol of the network **170**. As such, the wireless field devices **140-146**, the wireless gateway **135**, and other wireless nodes **152-158** of the wireless network **170** are producers and consumers of wireless communication packets.

In some configurations of the process plant **100**, the wireless network **170** includes non-wireless devices. For example, in FIG. **1**, a field device **148** of FIG. **1** is a legacy 4-20 mA device and a field device **150** is a wired HART® device. To communicate within the network **170**, the field devices **148** and **150** are connected to the wireless communications network **170** via a respective wireless adaptor **152**A, **152**B. The wireless adaptors **152**A, **152**B support a wireless protocol, such as WirelessHART, and may also support one or more other communication protocols such as Foundation® Fieldbus, PROFIBUS, DeviceNet, etc. Additionally, in some configurations, the wireless network **170** includes one or more network access points **155**A, **155**B, which may be separate physical devices in wired communication with the wireless gateway **135**, or may be provided with the wireless gateway **135** as an integral device. The wireless network **170** may also include one or more routers **158** to forward packets from one wireless device to another wireless device within the wireless communications network **170**. In FIG. **1**, the wireless devices **140-146** and **152-158** communicate with each other and with the wireless gateway **135** over wireless links **160** of the wireless communications network **170**, and/or via the process control data highway **110**.

In FIG. **1**, the process control system **100** includes one or more operator workstations **171** that are communicatively connected to the data highway **110**. Via the operator workstations **171**, operators may view and monitor run-time operations of the process plant **100**, as well as take any diagnostic, corrective, maintenance, and/or other actions that may be required. At least some of the operator workstations **171** may be located at various, protected areas in or near the plant **100**, e.g., in a back-end environment of the plant **100**, and in some situations, at least some of the operator workstations **171** may be remotely located, but nonetheless in communicative connection with the plant **100**. Operator workstations **171** may be wired or wireless computing devices.

The example process control system **100** is further illustrated as including a configuration application **172**A and configuration database **172**B, each of which is also communicatively connected to the data highway **110**. As discussed above, various instances of the configuration application **172**A may execute on one or more computing devices (not shown) to enable users to create or change process control modules and/or other types of modules, and download these modules via the data highway **110** to the controllers **111** and/or other devices of the process control system **100**, as well as enable users to create or change operator interfaces via which in operator is able to view data and change data settings within process control routines. The configuration database **172**B stores the created (e.g., configured) modules and/or operator interfaces. Generally, the configuration application **172**A and configuration database **172**B are centralized and have a unitary logical appearance to the process control system **100**, although multiple instances of the configuration application **172**A may execute simultaneously within the process control system **100**, and the configuration database **172**B may be implemented across multiple physical data storage devices. Accordingly, the configuration application **172**A, configuration database **172**B, and user interfaces thereto (not shown) comprise a configuration or development system **172** for control and/or display modules. Typically, but not necessarily, the user interfaces for the configuration system **172** are different than the operator workstations **171**, as the user interfaces for the configuration system **172** are utilized by configuration and development engineers irrespective of whether or not the plant **100** is operating in real-time, whereas the operator workstations **171** are utilized by operators during real-time operations of the process plant **100** (also referred to interchangeably here as "run-time" operations of the process plant **100**).

The example process control system **100** includes a data historian application **173**A and data historian database **173**B, each of which is also communicatively connected to the data highway **110**. The data historian application **173**A operates to collect some or all of the data provided across the data highway **110**, and to historize or store the data in the historian database **173**B for long term storage. Similar to the configuration application **172**A and configuration database **172**B, the data historian application **173**A and historian database **173**B are centralized and have a unitary logical appearance to the process control system **100**, although multiple instances of a data historian application **173**A may execute simultaneously within the process control system **100**, and the data historian **173**B may be implemented across multiple physical data storage devices.

In some configurations, the process control system **100** includes one or more other wireless access points **174** that communicate with other devices using other wireless protocols, such as Wi-Fi or other IEEE 802.11 compliant wireless local area network protocols, mobile communication protocols such as WiMAX (Worldwide Interoperability for Microwave Access), LTE (Long Term Evolution) or other ITU-R (International Telecommunication Union Radiocommunication Sector) compatible protocols, short-wavelength radio communications such as near field communications (NFC) and Bluetooth, or other wireless communication protocols. Typically, such wireless access points **174** allow handheld or other portable computing devices (e.g., user interface devices **175**) to communicate over a respective wireless process control communication network that is different from the wireless network **170** and that supports a different wireless protocol than the wireless network **170**. For example, a wireless or portable user interface device **175** may be a mobile workstation or diagnostic test equipment that is utilized by an operator within the process plant **100** (e.g., an instance of one of the operator workstations **171**). The wireless or portable user interface device **175** may also be a smartphone, tablet computer, laptop computer, or other device for receiving notifications utilized by a user, such as the operator, an engineer, an instrument technician, a maintenance person, or some other process plant personnel. In some scenarios, in addition to portable computing devices, one or more process control devices (e.g., controller **111**, field devices **115-122**, or wireless devices **135**, **140-158**) also communicate using the wireless protocol supported by the access points **174**.

In some configurations, the process control system **100** includes one or more gateways **176**, **178** to systems that are external to the immediate process control system **100**. Typically, such systems are customers or suppliers of information generated or operated on by the process control system **100**. For example, the process control plant **100** may include a gateway node **176** to communicatively connect the immediate process plant **100** with another process plant. Additionally or alternatively, the process control plant **100** may include a gateway node **178** to communicatively connect the immediate process plant **100** with an external public or private system, such as a laboratory system (e.g., Laboratory Information Management System or LIMS), an operator rounds database, a materials handling system, a maintenance management system, a product inventory control system, a production scheduling system, a weather data system, a shipping and handling system, a packaging system, the Internet, another provider's process control system, or other external systems.

It is noted that although FIG. **1** only illustrates a single controller **111** with a finite number of field devices **115-122** and **140-146**, wireless gateways **35**, wireless adaptors **152**, access points **155**, routers **1158**, and wireless process control communications networks **170** included in the example process plant **100**, this is only an illustrative and non-limiting embodiment. Any number of controllers **111** may be included in the process control plant or system **100**, and any of the controllers **111** may communicate with any number of wired or wireless devices and networks **115-122**, **140-146**, **135**, **152**, **155**, **158** and **170** to control a process in the plant **100**.

One of the duties of an operator may be to monitor run-time operations of the process plant **100** via the operator workstation **171** or portable user interface device **175** for suspect valves. When a suspect valve is detected, the operator workstation **171** may present an indication on the user interface of the suspect valve, such as a status, an alert, an alarm, or a notification. Then the operator may respond to the indication by monitoring the performance of the valve further to ensure that the valve is not operating well and shut down operation of the process when the valve is not operating well to repair or replace the valve. In other implementations, the process may automatically shut down (e.g., from a control signal from the operator workstation **171** or another computing device) in response to determining that a valve is not operating well. Other users, for example the control engineer, maintenance technician, instrument technician, or some other process plant personnel may also perform valve monitoring duties via the operator workstation **171** or portable user interface device **175**.

To determine the status of a valve, a computing device such as the operator workstation **171** or portable user interface device **175** receives sensor data from the controller, field devices, and/or process plant entities (e.g., pumps, tanks, mixers, etc.) within the process control system **100**. The sensor data may include process parameter values for process parameters related to the valve, such as valve travel values, controller output values, SP values, or PV values for a process plant entity coupled to the valve. The computing device may obtain these values at several instances over a particular time period (e.g., 30 minutes). Then the computing device may estimate performance metrics for the valve, such as the change in the controller output, the change in valve travel, the change in the PV, and/or the dead band over the time period using the valve travel values, controller output values, SP values, and/or PV values for the time period. The computing device may then determine the status of the valve for the time period based on the estimated change in the controller output, the estimated change in valve travel, and/or the estimated dead band over the time period.

In some implementations, the computing device uses valve travel values to determine the status of the valve when valve travel values are available. Otherwise, when the valve travel values are unavailable or inaccessible, the computing device uses PV values to determine the status of the valve.

Also in some implementations, the computing device estimates the change in the controller output, change in the PV, and/or the dead band over the time period using an ellipse fitting algorithm. For example, the computing device may plot a graph of the PV values as a function of the controller output values, fit an ellipse to the values, and use characteristics of the ellipse to estimate the change in the controller output, the change in PV, and/or the dead band over the time period. FIG. **3** illustrates a first example graph **300** of controller output values and process variable values as a function of time, and a second example graph **350** of the process variable values as a function of the controller output values. To estimate the change in the controller output, change in the PV, and/or the dead band, the computing device fits an ellipse **352** to the values in the graph **350**. Then the computing device identifies characteristics of the ellipse, such as a length of a major axis of the ellipse, a length of a minor axis of the ellipse, and an angle of rotation of the ellipse. The computing device then estimates the change in the controller output, change in the PV, and/or the dead band using the characteristics of the ellipse. More specifically, the computing device estimates the change in the controller output, change in the PV, and/or the dead band according to the following equations:

$$\text{Deadband } Est. = \frac{2\,mn}{\sqrt{m^2\sin^2\varphi + n^2\cos^2\varphi}} \tag{1}$$

$$\Delta\text{OUT } Est. = 2\sqrt{m^2\cos^2\varphi + n^2\sin^2\varphi} \tag{2}$$

$$\Delta PV\ Est. = 2\sqrt{m^2\sin^2\varphi + n^2\cos^2\varphi} \tag{2}$$

where m is the length of the major access of the ellipse, n is the length of the minor access of the ellipse, and φ is the angle of rotation of the ellipse.

Then the computing device may compare the dead band estimate to a threshold dead band percentage (e.g., 2%). The computing device may also compare the product of the change in the controller output (ΔOUT Est) and a process gain (K_p) to the change in PV (ΔPV Est.) or the change in PV (ΔPV Est.) multiplied by a predetermined constant (γ), where γ may be between 1 and 1.1. If the dead band estimate is less than or equal to the threshold dead band percentage (Deadband Est.≤2%), and/or the product of the change in the controller output and the process gain (K_p) is less than or equal to the change in PV multiplied by the predetermined constant (ΔOUT Est.*K_p≤γΔPV Est.), the computing device determines that the valve is operating well for the particular time period. Otherwise, the computing device determines that the status of the valve is suspect for the particular time period. In some implementations, the computing device then provides an indication on a user interface of the suspect valve, such as an alert, an alarm, or a notification. In other implementations, the computing device analyzes the status of the valve over N time periods before making a final determination of whether or not the valve is suspect and providing a status, an alert, an alarm, or a notification to the user.

In some scenarios, such as when valve travel values are available, the ellipse fitting algorithm may overestimate the change in controller output, change in valve travel/valve position readback (RB), and/or dead band metrics. For example, when the system is set to the automatic mode, and at steady state without any SP changes or load disturbances the valve only goes through continuous stick-jump steps as shown in FIG. **4**A, the ellipse fitting algorithm may overestimate these metrics. In this scenario, the computing device may use a valve index calculation to estimate the change in controller output, change in RB, and/or dead band.

FIG. **4**A illustrates an example graph **400** of controller output values and valve travel values as a function of time. As shown in the graph **400**, the valve travel values step or jump from one value to the next in a step function. FIG. **4**B illustrates an example graph **430** of the valve travel values as a function of the controller output values. The values in the graph **430** form a rectangular shape **432**, and the ellipse **434** overestimates the values in the graph **430**. Accordingly, the computing device uses a valve index calculation instead of an ellipse fitting algorithm. The computing device uses the coordinates of the four vertices of the rectangular shape **432** and estimates dead band and valve jump using the coordinates. More specifically, the computing device estimates the change in the controller output, change in RB, and/or the dead band according to the following equations:

$$\text{Deadband } Est. = \Delta\text{OUT } Est. = \frac{H_{max} - H_{min} + H_{S_{max}} - H_{S_{min}}}{2} \tag{4}$$

$$\text{Jump} = \Delta RB\ Est. = -\frac{H_{S_{max}} - H_{max} + H_{min} - H_{S_{min}}}{2} \tag{5}$$

where H_{max} is the lower right coordinate (x_2, y_2), H_{min} is the upper left coordinate (x_4, y_4), $H_{S_{max}}$ is the upper right coordinate (x_3, y_3), and $H_{S_{min}}$ is the lower left coordinate (x_1, y_1), of the rectangle **462** shown in FIG. **4**C. In some implementations, the computing device first determines the change in controller output, change in RB, and/or dead band using the ellipse fitting algorithm. Then the computing device may switch to using the valve index calculation instead of the ellipse fitting algorithm when the change in controller output subtracted by the change in RB (ΔOUT Est.–ΔRB Est.) is greater than or equal to a threshold difference (e.g., 5%).

In some scenarios, process dynamics may influence the process which may result in an increase in false positive suspect valve detections. This occurs more frequently when the controller is in the manual mode, where process dynamics may exaggerate the dead band estimation. In these scenarios, dynamic controller output values are used instead of controller output values to determine the status of the valve for example, using an ellipse fitting algorithm or a valve index calculation. FIG. **5** illustrates an example block diagram **500** of the relationship between controller output values **502** and dynamic controller output values **504**. More specifically, dynamic controller output values are determined according to the following equation:

$$\text{OUT}_{dynamic} = \text{OUT} * \frac{K_p}{TC * s + DT} \tag{6}$$

The computing device determines the process gain (K_p), dead time (DT), and time constant (TC) at a particular instance in time based on differences between the SP value, the controller output value, and/or the PV value at the particular instance in time using a model estimation algorithm. For example, the DT may be determined based on a time difference between the time when the controller output value changes and a time when the PV value begins to change. The TC may be determined based on a time difference between the time when the PV value begins to change and the PV value reaches a threshold proportion (e.g., 63%) of the total change in the PV value as a result of the change in the controller output value. The process gain may be determined as the ratio of the change in the rate of change of the PV and the change in the controller output.

The computing device may determine the dynamic controller output values according to Eq. 6. Then the computing device may estimate the change in the controller output, change in the PV/valve travel, and/or the dead band by plotting a graph of the PV/valve travel values as a function of the dynamic controller output values, fitting an ellipse to the values, and using characteristics of the ellipse. In other implementations, the computing device may plot a graph of the PV/valve travel values as a function of the dynamic controller output values and may use the valve index calculation to estimate the change in the controller output, change in the PV/change in valve travel, and/or the dead band.

FIG. **6** illustrates an example comparison of a dead band estimation using an ellipse fitting algorithm by plotting a first graph **600** of PV values as a function of controller output values and plotting a second graph **650** of PV values as a function of dynamic controller output values. Using the ellipse **602** that is fit to the first graph **600** which does not include dynamic controller output values, the computing device estimates the dead band at 12.38% which may result in the computing device identifying the status of the valve as suspect. By contrast, using the ellipse **652** that is fit to the second graph **652** which includes dynamic controller output values, the computing device estimates the dead band at 0.21% which may result in the computing device identifying the status of the valve as good. Using dynamic controller output values in this scenario prevents a false positive suspect valve detection when the threshold dead band percentage is 1% or 2%, for example.

In addition or as an alternative to determining the status of the valve based on the dead band determined using the dynamic controller output values, the computing device may determine the status of the valve based on the change in the controller output and/or change in the PV/valve travel using the dynamic controller output values. In some implementations, the computing device then determines based on the status of the valve whether to provide an indication on a user interface of a suspect valve, such as a status, an alert, an alarm, or a notification. In other implementations, the computing device analyzes the status of the valve over N time periods before making a final determination of whether or not the valve is suspect and providing a status, an alert, an alarm, or a notification to the user.

FIG. **7** is a flow diagram of an example method **700** for detecting a suspect valve in a process plant **100** using a moving time window when valve travel data is available, which may be implemented by a computing device such as an operator workstation **171** or a portable user interface device **175**.

At block **702**, the computing device determines that valve travel data is available and determines to use the valve travel (RB), SP, and controller output values to determine the status of the valve. In some implementations, the computing device uses dynamic controller output values instead of controller output values (e.g., when the controller is in the manual mode) by combining the controller output values with process dynamics, such as the process gain, dead time, and the time constant.

At block **704**, the computing device selects N time periods or windows for determining the status of the valve. The computing device may select the duration of each moving time window, and the number of N time windows. In some implementations, each time period/window may have an equal duration. Also in some implementations, the computing device may select the duration of each moving time window based on the type of process that the controller **111** is executing. For example, if the process is a self-regulating process, the computing device may select a moving time window of 30 minutes. If the process is integrating, the computing device may select a moving time window of 60 minutes. More specifically, the computing device may select the duration of each moving time window according to the following equations for a self-regulating process and an integrating process, respectively:

$$h=\max(1800,120*\text{Reset}) \tag{7}$$

$$h=\max(3600,50*\text{Reset}) \tag{8}$$

where h is the duration in seconds of the moving time window, and Reset is the reset value or time constant (TC) of the process.

The computing device may also select a sampling rate at which to collect valve travel, controller output, and/or SP values within each time period. For example, the computing device may collect new valve travel, controller output, and/or SP values once per second, once per minute, etc. In some implementations, the computing device may set the sampling rate to the rate at which the controller **111** changes the SP or the controller output. The sampling rate may be affected by the process time constant (TC in FIG. **5**).

Then at blocks **706** and **708**, the computing device obtains the controller output values (OUT_i), SP values (SP_i), and valve travel values (RB_i) for the current (i) time period of the N time periods. The controller output values, SP values, and valve travel values may each include an array of values where the number of elements in each array is based on the sampling rate and the duration of the time period.

At block **710**, the computing device executes an ellipse fitting algorithm for the ith time period by plotting a graph of RB_i as a function of OUT_i and fitting an ellipse to the values in the graph. The computing device then identifies characteristics of the ellipse, such as a length of a major axis of the ellipse, a length of a minor axis of the ellipse, and an angle of rotation of the ellipse. The computing device then estimates the change in the controller output (ΔOUT), change in the valve travel (ΔRB), and/or the dead band for the ith time period using the characteristics of the ellipse according to Eqs. (1)-(3) as shown above (block **712**).

At block **714**, the computing device compares ΔOUT to ΔRB to determine whether to use a valve index calculation to determine ΔOUT, ΔRB, and the dead band estimate instead of the ellipse fitting algorithm. For example, the computing device may switch to using the valve index calculation when ΔOUT subtracted by ΔRB is greater than or equal to a threshold difference (e.g., 5%). If ΔOUT subtracted by ΔRB is greater than or equal to a threshold difference, the computing device uses the valve index calculation (block **716**), and updates the ΔOUT, ΔRB, and dead band estimates for the ith time period using the valve index calculation (block **718**). More specifically, the computing device uses the coordinates of the four vertices of the rectangular shape **432** formed by the graph of RB_i as a function of OUT_i and estimates ΔOUT, ΔRB, and dead band according to Eqs. (4) and (5) as shown above.

Then at block **720**, the computing device determines the status of the valve for the ith time period using the ΔOUT, ΔRB, and the dead band estimates determined via the ellipse fitting algorithm (block **712**) or the valve index calculation (block **718**). In some implementations, the status of the valve may be good, suspect, or another status indicating that the valve status should be ignored for the ith time period, such as a set point change. The method for determining the status of the valve is described in more detail with reference to FIG. **8**.

As shown in FIG. **8**, at block **802** the computing device uses the ΔOUT_i, ΔRB_i, and the dead band estimates for the ith time period to determine the status of the valve at the ith time period. At block **804**, the computing device determines whether the process type for the process executed by the controller **111** is an integrating process. If the process is an integrating process, any set point change ($SP_i>0$) will result in the computing device determining the valve status is a set point change and the valve status will be ignored for the ith time period (block **806**). Otherwise, if the process type is another process type such as a self-regulating process, the change in the set point value (SP_i) is compared to a threshold set point change (e.g., 1%) (block **808**). If SP_i exceeds the threshold set point change (e.g., $SP_i>1\%$), computing device determines the valve status is a set point change and the valve status will be ignored for the ith time period.

Otherwise, if the set point change does not exceed the threshold set point change for the corresponding process type, the computing device determines the mode of operation of the controller **111** (block **810**). If the controller **111** is being operated in the manual mode, the computing device compares the dead band estimate to a threshold dead band percentage (e.g., 2%) (block **814**). If the dead band estimate for the ith time period exceeds the threshold dead band percentage, the computing device determines the valve status is suspect for the ith time period. On the other hand, if the dead band estimate for the ith time period does not exceed the threshold dead band percentage, the computing device determines the valve status is good for the ith time period.

If the controller **111** is not being operated in the manual mode and is instead being operated in the automatic mode for example, the computing device compares the dead band estimate to the threshold dead band percentage (e.g., 2%) and compares ΔOUT_i to ΔRB_i multiplied by a predetermined constant (γ), where γ may be between 1 and 1.1 (block **812**). If the dead band estimate is greater than the threshold dead band percentage and ΔOUT_i is greater than $\gamma\Delta RB_i$, the computing device determines the valve status is suspect for the ith time period. Otherwise, the computing device determines the valve status is good for the ith time period.

Turning back to FIG. **7**, in response to determining the status of the valve for the ith time period, the computing device determines whether i is equal to N (block **722**). If i is not equal to N, the computing device increments i and determines the status of the valve for the next time period (block **708**). The computing device then repeats this process for each time period until i is equal to N.

In response to determining that i is equal to N, and the valve status has been determined for each of the N time periods, the computing device generates a set of valve statuses for each of the N time periods (block **724**), and calculates a proportion or percentage of the time periods in which the valve status is good (block **726**). In some implementations, the computing device removes or ignores valve statuses which are not either good or suspect. Then the computing device calculates a proportion or percentage of the remaining subset of the N time periods in which the valve status is good. For example, as shown in FIG. **11**A, the computing device determines the valve status for 45 time periods. Over the N moving time windows/periods, the valve status is good 20 times, the valve status is suspect 22 times, and the valve status is neither good nor suspect 3 times where the status is set point change. Accordingly, the computing device removes or ignores the valve status for 3 instances, and calculates the proportion or percentage of the remaining subset of 42 out of the 45 time periods in which the valve status is good as 20 divided by 42 or 47.62% as shown in FIG. **11**B.

The computing device then compares the proportion or percentage to a threshold proportion or percentage (e.g., 20%) to determine whether or not the valve is a suspect valve. If the proportion or percentage of the remaining subset of the N time periods in which the valve status is good does not exceed the threshold proportion or percentage, the computing device determines that the valve is a suspect valve. Then the computing device may provide an indication on the user interface of the suspect valve, such as a status, an alert, an alarm, or a notification. The user may respond to the status, alert, alarm, or notification by monitoring the performance of the valve further to ensure that the valve is not operating well and shut down operation of the process when the valve is not operating well to repair or replace the valve. In other implementations, the process may automatically shut down (e.g., from a control signal from the operator workstation **171** or another computing device) in response to determining that a valve is suspect.

In other implementations, valve travel data is unavailable or inaccessible. For example, the valve is not communicatively coupled to a valve travel sensor. FIG. **9** is a flow diagram of an example method **900** for detecting a suspect valve in a process plant using a moving time window when valve travel data is unavailable, which may be implemented by a computing device such as an operator workstation **171** or portable user interface device **175**.

At block **902**, the computing device determines that valve travel data is unavailable and determines to use the PV, SP, and controller output values to determine the status of the valve. In some implementations, the computing device uses dynamic controller output values instead of controller output values (e.g., when the controller is in the manual mode) by combining the controller output values with process dynamics, such as the process gain, dead time, and the time constant.

At block **904**, the computing device selects N time periods or windows for determining the status of the valve. The computing device may select the duration of each moving time window, and the number of N time windows. In some implementations, each time period/window may have an equal duration. Also in some implementations, the computing device may select the duration of each moving time window based on the type of process that the controller **111** is executing. For example, if the process is a self-regulating process, the computing device may select a moving time window of 30 minutes. If the process is integrating, the computing device may select a moving time window of 60 minutes. More specifically, the computing device may select the duration of each moving time window according to Eqs. 7 and 8.

The computing device may also select a sampling rate at which to collect PV, controller output, and/or SP values within each time period. For example, the computing device may collect new PV, controller output, and/or SP values once per second, once per minute, etc. In some implementations, the computing device may set the sampling rate to the rate at which the controller **111** changes the SP or the controller output.

Then at blocks **906** and **908**, the computing device obtains the controller output values (OUT_i), SP values (SP_i), and PV values (PV_i) for the current (i) time period of the N time periods. The controller output values, SP values, and PV values may each include an array of values where the number of elements in each array is based on the sampling rate and the duration of the time period.

At block **910**, the computing device executes an ellipse fitting algorithm for the ith time period by plotting a graph of PV_i as a function of OUT_i and fitting an ellipse to the values in the graph. The computing device then identifies characteristics of the ellipse, such as a length of a major axis of the ellipse, a length of a minor axis of the ellipse, and an angle of rotation of the ellipse. The computing device then estimates the change in the controller output (ΔOUT), change in the valve travel (ΔPV), and/or the dead band for the ith time period using the characteristics of the ellipse according to Eqs. (1)-(3) as shown above (block **912**).

Then at block **914**, the computing device determines the status of the valve for the ith time period using the ΔOUT, ΔRB, and the dead band estimates. In some implementations, the status of the valve may be good, suspect, or another status indicating that the valve status should be ignored for the ith time period, such as a set point change. The method for determining the status of the valve is described in more detail with reference to FIG. **10**.

As shown in FIG. **10**, at block **1002** the computing device uses the ΔOUT_i, ΔPV_i, and the dead band estimates for the ith time period to determine the status of the valve at the ith time period. At block **1004**, the computing device determines whether the process type for the process executed by the controller **111** is an integrating process. If the process is an integrating process, any set point change ($SP_i>0$) will result in the computing device determining the valve status is a set point change and the valve status will be ignored for the ith time period (block **1006**). Otherwise, if the process type is another process type such as a self-regulating process, the change in the set point value (SP_i) is compared to a threshold set point change (e.g., 1%) (block **1008**). If SP_i exceeds the threshold set point change (e.g., $SP_i>1\%$), computing device determines the valve status is a set point change and the valve status will be ignored for the ith time period.

Otherwise, if the set point change does not exceed the threshold set point change for the corresponding process type, the computing device determines the mode of operation of the controller **111** (block **1010**). If the controller **111** is being operated in the manual mode, the computing device compares the dead band estimate to a threshold dead band percentage (e.g., 2%) (block **1014**). If the dead band estimate for the ith time period exceeds the threshold dead band percentage, the computing device determines the valve status is suspect for the ith time period. On the other hand, if the dead band estimate for the ith time period does not exceed the threshold dead band percentage, the computing device determines the valve status is good for the ith time period.

If the controller **111** is not being operated in the manual mode and is instead being operated in the automatic mode for example, the computing device determines if the process type is self-regulating and a process gain (K_p) is available (block **1011**). If the process is not self-regulating or the process gain is unavailable, the computing device compares the dead band estimate to the threshold dead band percentage (e.g., 2%) (block **1014**) as described above. Otherwise, if the process is self-regulating and has a process gain, the computing device compares the dead band estimate to the threshold dead band percentage (e.g., 2%) and compares product of ΔOUT_i and K_p to ΔPV_i multiplied by a predetermined constant (γ), where γ may be between 1 and 1.1. If the dead band estimate is greater than the threshold dead band percentage and ΔOUT_i*K_p is greater than $\gamma\Delta PV_i$, the computing device determines the valve status is suspect for the ith time period. Otherwise, the computing device determines the valve status is good for the ith time period.

Turning back to FIG. **9**, in response to determining the status of the valve for the ith time period, the computing device determines whether i is equal to N (block **916**). If i is not equal to N, the computing device increments i and determines the status of the valve for the next time period (block **908**). The computing device then repeats this process for each time period until i is equal to N.

In response to determining that i is equal to N, and the valve status has been determined for each of the N time periods, the computing device generates a set of valve statuses for each of the N time periods (block **918**), and calculates a proportion or percentage of the time periods in which the valve status is good (block **920**). In some implementations, the computing device removes or ignores valve statuses which are not either good or suspect. Then the computing device calculates a proportion or percentage of the remaining subset of the N time periods in which the valve status is good.

The computing device then compares the proportion or percentage to a threshold proportion or percentage (e.g., 20%) to determine whether or not the valve is a suspect valve. If the proportion or percentage of the remaining subset of the N time periods in which the valve status is good does not exceed the threshold proportion or percentage, the computing device determines that the valve is a suspect valve. Then the computing device may provide an indication on the user interface of the suspect valve, such as a status, an alert, an alarm, or a notification. The user may respond to the status, alert, alarm, or notification by monitoring the performance of the valve further to ensure that the valve is not operating well and shut down operation of the process when the valve is not operating well to repair or replace the valve. In other implementations, the process may automatically shut down (e.g., from a control signal from the operator workstation **171** or another computing device) in response to determining that a valve is suspect.

When implemented in software, any of the applications, services, and engines described herein may be stored in any tangible, non-transitory computer readable memory such as on a magnetic disk, a laser disk, solid state memory device, molecular memory storage device, or other storage medium, in a RAM or ROM of a computer or processor, etc. Although the example systems disclosed herein are disclosed as including, among other components, software and/or firmware executed on hardware, it should be noted that such systems are merely illustrative and should not be considered as limiting. For example, it is contemplated that any or all of these hardware, software, and firmware components could be embodied exclusively in hardware, exclusively in software, or in any combination of hardware and software. Accordingly, while the example systems described herein are described as being implemented in software executed on a processor of one or more computer devices, persons of ordinary skill in the art will readily appreciate that the examples provided are not the only way to implement such systems.

Thus, while the present invention has been described with reference to specific examples, which are intended to be illustrative only and not to be limiting of the invention, it will be apparent to those of ordinary skill in the art that changes, additions or deletions may be made to the disclosed embodiments without departing from the spirit and scope of the invention.

The particular features, structures, and/or characteristics of any specific embodiment may be combined in any suitable manner and/or in any suitable combination with one and/or more other embodiments, including the use of selected features with or without corresponding use of other features. In addition, many modifications may be made to adapt a particular application, situation and/or material to the essential scope or spirit of the present invention. It is to be understood that other variations and/or modifications of the embodiments of the present invention described and/or illustrated herein are possible in light of the teachings herein and should be considered part of the spirit or scope of the present invention. Certain aspects of the invention are described herein as exemplary aspects.

What is claimed is:

1. A method for detecting a suspect valve in a process plant, the method comprising:

for each of N time periods:

determining, by one or more processors, one or more process parameter values for one or more process parameters related to a valve during the time period; and

analyzing, by the one or more processors, the one or more process parameter values to determine a plurality of performance metrics for the valve including a change in controller output, a dead band value, and at least one of: a change in valve travel or a change in a process variable value; and

determining a status of the valve for the time period by comparing the dead band value to a threshold dead band percentage and comparing at least one of: (i) the change in controller output to the change in valve travel or (ii) the product of the change in controller output and a process gain value to the change in the process variable value;

comparing, by the one or more processors, the valve statuses over the N time periods to determine whether the valve is operating well for at least a threshold portion of at least a subset of the N time periods;

in response to determining that the valve is not operating well for at least the threshold portion of at least the subset of the N time periods, determining that the valve is a suspect valve; and

providing, by the one or more processors, an indication of the suspect valve to a user interface for display to a user.

2. The method of claim **1**, wherein the one or more process parameters include at least one of: a valve travel, a controller output, a set point, a process gain, or a process variable.

3. The method of claim **1**, wherein

in response to determining that the dead band value is greater than the threshold dead band percentage and the change in controller output exceeds the change in valve travel, determining the suspect status for the valve for the time period.

4. The method of claim **3**, further comprising:

in response to determining that the dead band value is not greater than the threshold dead band percentage or the change in controller output does not exceed the change in valve travel, determining a good operation status for the valve for the time period.

5. The method of claim **4**, further comprising:

determining an operating mode for a process executing the process plant;

in a first instance:

in response to determining that the operating mode is manual, comparing the dead band value to the threshold dead band percentage to determine the valve status; and

in a second instance:

in response to determining that the operating mode is automatic, comparing the dead band value to the threshold dead band percentage and the change in controller output to the change in valve travel to determine the valve status.

6. The method of claim **5**, further comprising:

determining a process type for the process;

determining a change in a set point value for the time period;

in response to determining that the process type is an integrating process, comparing the change in the set point value to a first threshold change in set point; and

in response to determining that the change in the set point value exceeds the first threshold change in set point, determining a set point change status for the valve.

7. The method of claim **6**, further comprising:

in response to determining that the process type is not an integrating process, comparing the change in the set point value to a second threshold change in set point; and

in response to determining that the change in the set point value exceeds the second threshold change in set point, determining the set point change status for the valve.

8. The method of claim **7**, wherein the operating mode for the process is determined in response to determining that the change in the set point value does not exceed the first threshold when the process type is the integrating process or that the change in the set point value does not exceed the second threshold when the process type is not the integrating process.

9. The method of claim **1**, wherein determining a status of the valve includes:

in response to determining that the dead band value is greater than the threshold dead band percentage and the product of the change in controller output and the process gain value exceeds the change in the process variable value, determining the suspect status for the valve for the time period.

10. The method of claim **9**, further comprising:

in response to determining that the dead band value is not greater than the threshold dead band percentage or the product of the change in controller output and the process gain value does not exceed the change in the process variable value, determining a good operation status for the valve for the time period.

11. The method of claim **10**, further comprising:

determining an operating mode for a process executing the process plant;

in a first instance:

in response to determining that the operating mode is manual, comparing the dead band value to the threshold dead band percentage to determine the valve status; and in a second instance:

in response to determining that the operating mode is automatic, comparing the dead band value to the threshold dead band percentage and the product of the change in controller output and the process gain value to the change in the process variable to determine the valve status.

12. The method of claim **11**, further comprising:

determining a process type for the process;

determining a change in a set point value for the time period;

in response to determining that the process type is an integrating process, comparing the change in the set point value to a first threshold change in set point; and

in response to determining that the change in the set point value exceeds the first threshold change in set point, determining a set point change status for the valve.

13. The method of claim **12**, further comprising:

in response to determining that the process type is not an integrating process, comparing the change in the set point value to a second threshold change in set point; and

in response to determining that the change in the set point value exceeds the second threshold change in set point, determining the set point change status for the valve.

14. The method of claim **13**, wherein the operating mode for the process is determined in response to determining that the change in the set point value does not exceed the first threshold when the process type is the integrating process or that the change in the set point value does not exceed the second threshold when the process type is not the integrating process.

15. The method of claim **1**, further comprising:

shutting down operation of a process executing within the process plant in response to detecting the suspect valve.

16. The method of claim **1**, wherein analyzing one or more process parameter values includes:

analyzing the one or more process parameter values to determine at least one of the dead band value, the change in controller output, the change in a process variable value, or the change in valve travel using an ellipse fitting algorithm.

17. The method of claim **16**, wherein determining at least one of the dead band value, the change in controller output, the change in the process variable value, or the change in valve travel using an ellipse fitting algorithm includes:

plotting a graph of valve travel values as a function of controller output values;

fitting an ellipse to the graph; and

determining the dead band value, the change in controller output, and the change in valve travel based on one or more characteristics of the ellipse.

18. The method of claim **17**, wherein the one or more characteristics of the ellipse include a length of a major axis of the ellipse, a length of a minor axis of the ellipse, and an angle of rotation of the ellipse.

19. The method of claim **16**, wherein determining at least one of the dead band value, the change in controller output, the change in the process variable value, or the change in valve travel using an ellipse fitting algorithm includes:

plotting a graph of process variable values as a function of controller output values;

fitting an ellipse to the graph; and

determining the dead band value, the change in controller output, and the change in the process variable value based on one or more characteristics of the ellipse.

20. The method of claim **19**, wherein the one or more characteristics of the ellipse include a length of a major axis of the ellipse, a length of a minor axis of the ellipse, and an angle of rotation of the ellipse.

21. A computing device for detecting a suspect valve in a process plant, the computing device comprising:

one or more processors; and

a non-transitory computer-readable memory coupled to the one or more processors and storing instructions thereon that, when executed by the one or more processors, cause the computing device to:

for each of N time periods:

determine one or more process parameter values for one or more process parameters related to a valve during the time period; and

analyze the one or more process parameter values to determine a plurality of performance metrics for the valve including a change in controller output, a dead band value, and at least one of: a change in valve travel or a change in a process variable value; and

determine a status of the valve for the time period by comparing the dead band value to a threshold dead band percentage and comparing at least one of: (i) the change in controller output to the change in valve travel or (ii) the product of the change in controller output and a process gain value to the change in the process variable value;

compare the valve statuses over the N time periods to determine whether the value is operating well for at least a threshold portion of at least a subset of the N time periods;

in response to determining that the valve is not operating well for at least the threshold portion of at least the subset of the N time periods, determine that the valve is a suspect valve; and

provide an indication of the suspect valve to a user interface for display to a user.

22. The computing device of claim **21**, wherein the one or more process parameters include at least one of: a valve travel, a controller output, a set point, a process gain, or a process variable.

23. The computing device of claim **21**, wherein the instructions further cause the computing device to:

in response to determining that the dead band value is greater than the threshold dead band percentage and the change in controller output exceeds the change in valve travel, determine the suspect status for the valve for the time period.

24. The computing device of claim **23**, wherein the instructions further cause the computing device to:

in response to determining that the dead band value is not greater than the threshold dead band percentage or the change in controller output does not exceed the change in valve travel, determine a good operation status for the valve for the time period.

25. The computing device of claim **21**, wherein to determine a status of the valve, the instructions further cause the computing device to:

in response to determining that the dead band value is greater than the threshold dead band percentage and the product of the change in controller output and the process gain value exceeds the change in the process variable value, determine the suspect status for the valve for the time period.

26. The computing device of claim **25**, wherein the instructions further cause the computing device to:

in response to determining that the dead band value is not greater than the threshold dead band percentage or the product of the change in controller output and the process gain value does not exceed the change in the process variable value, determine a good operation status for the valve for the time period.

27. A process control system comprising:

a controller configured to control a valve;

the valve configured to control operation of a process plant entity executing within a process plant; and

a computing device including:

one or more processors; and

a non-transitory computer-readable memory coupled to the one or more processors and storing instructions thereon that, when executed by the one or more processors, cause the computing device to:

for each of N time periods:

determine one or more process parameter values for one or more process parameters related to the valve during the time period; and

analyze the one or more process parameter values to determine a plurality of performance metrics for the valve including a change in controller output, a dead band value, and at least one of: a change in valve travel or a change in a process variable value; and

determine a status of the valve for the time period by comparing the dead band value to a threshold dead band percentage and comparing at least one of: (i) the change in controller output to the change in valve travel or (ii) the product of the change in controller output and a process gain value to the change in the process variable value;

compare the valve statuses over the N time periods to determine whether the value is operating well for at least a threshold portion of at least a subset of the N time periods;

in response to determining that the valve is not operating well for at least the threshold portion of at least the subset of the N time periods, determine that the valve is a suspect valve; and

provide an indication of the suspect valve to a user interface for display to a user.

28. The process control system of claim **27**, wherein the one or more process parameters include at least one of: a valve travel, a controller output, a set point, a process gain, or a process variable.

29. The process control system of claim **27**, wherein to determine a status of the valve, the instructions further cause the computing device to:

compare the change in controller output to the change in valve travel over the time period; and

in response to determining that the dead band value is greater than the threshold dead band percentage and the change in controller output exceeds the change in valve travel, determine the suspect status for the valve for the time period.

30. The process control system of claim **29**, wherein the instructions further cause the computing device to:

in response to determining that the dead band value is not greater than the threshold dead band percentage or the change in controller output does not exceed the change in valve travel, determine a good operation status for the valve for the time period.

31. The process control system of claim **27**, wherein to determine a status of the valve, the instructions further cause the computing device to:

in response to determining that the dead band value is greater than the threshold dead band percentage and the product of the change in controller output and the process gain value exceeds the change in the process variable value, determine the suspect status for the valve for the time period.

32. The process control system of claim **31**, wherein the instructions further cause the computing device to:

in response to determining that the dead band value is not greater than the threshold dead band percentage or the product of the change in controller output and the process gain value does not exceed the change in the process variable value, determine a good operation status for the valve for the time period.

33. A method for reducing a false alarm rate in suspect valve detection using a moving time window, the method comprising:

determining, by one or more processors, a status of a valve in a process plant for each of N time periods by determining a plurality of performance metrics for the valve including a change in controller output, a dead band value, and at least one of: a change in valve travel or a change in a process variable value, comparing the dead band value to a threshold dead band percentage and comparing at least one of: (i) the change in controller output to the change in valve travel or (ii) the product of the change in controller output and a process gain value to the change in the process variable value;

determining, by the one or more processors, a proportion of at least a subset of the N time periods in which the valve status indicates the valve is operating well; and

providing, by the one or more processors, an indication that the valve is a suspect valve to a user interface for display to a user in response to determining that the proportion is less than a threshold proportion.

34. The method of claim **33**, wherein determining the status of the valve includes:

determining, by the one or more processors, one or more process parameter values for one or more process parameters related to the valve during each of the N time periods; and

analyzing, by the one or more processors, the one or more process parameter values to determine the plurality of performance metrics.

35. The method of claim **34**, wherein the one or more process parameters include at least one of: a valve travel, a controller output, a set point, a process gain, or a process variable.

36. The method of claim **34**, wherein analyzing the one or more process parameter values includes:

analyzing the one or more process parameter values to determine at least one of the dead band value, the change in controller output, the change in the process variable value, or the change in valve travel using an ellipse fitting algorithm.

37. The method of claim **36**, wherein determining at least one of the dead band value, the change in controller output, or the change in valve travel using an ellipse fitting algorithm includes:

plotting a graph of valve travel values as a function of controller output values;

fitting an ellipse to the graph; and

determining at least one of the dead band value, the change in controller output, or the change in valve travel based on one or more characteristics of the ellipse.

38. A method for detecting a suspect valve in a process plant, the method comprising:

determining, by one or more processors, one or more dynamic process parameter values for one or more dynamic process parameters related to a valve, the one or more dynamic process parameters including a dynamic controller output which is a controller output multiplied by a process gain divided by a combination of a time constant and a dead time;

analyzing, by the one or more processors, the one or more dynamic process parameter values including the dynamic controller output to determine a status of the valve; and

providing, by the one or more processors, an indication that the valve is a suspect valve in accordance with the status of the valve to a user interface for display to a user.

39. The method of claim **38**, further comprising:

determining, by the one or more processors, the status of the valve for each of N time periods,

wherein providing an indication that the valve is a suspect valve includes providing the indication in response to determining that the valve is not operating well for at least a threshold portion of at least a subset of the N time periods based on the valve statuses for the N time periods.

40. The method of claim **38**, wherein analyzing the one or more dynamic process parameter values includes:

analyzing the one or more dynamic process parameter values to determine at least one of a dead band value, a change in controller output, or a change in a process variable value using an ellipse fitting algorithm.

41. The method of claim **40**, wherein determining at least one of the dead band value, the change in controller output, or the change in the process variable value using an ellipse fitting algorithm includes:

plotting a graph of process variable values as a function of dynamic controller output values;

fitting an ellipse to the graph; and

determining at least one of the dead band value, the change in controller output, or the change in the process variable value based on one or more characteristics of the ellipse.

42. The method of claim **41**, wherein the one or more characteristics of the ellipse include a length of a major axis of the ellipse, a length of a minor axis of the ellipse, and an angle of rotation of the ellipse.

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