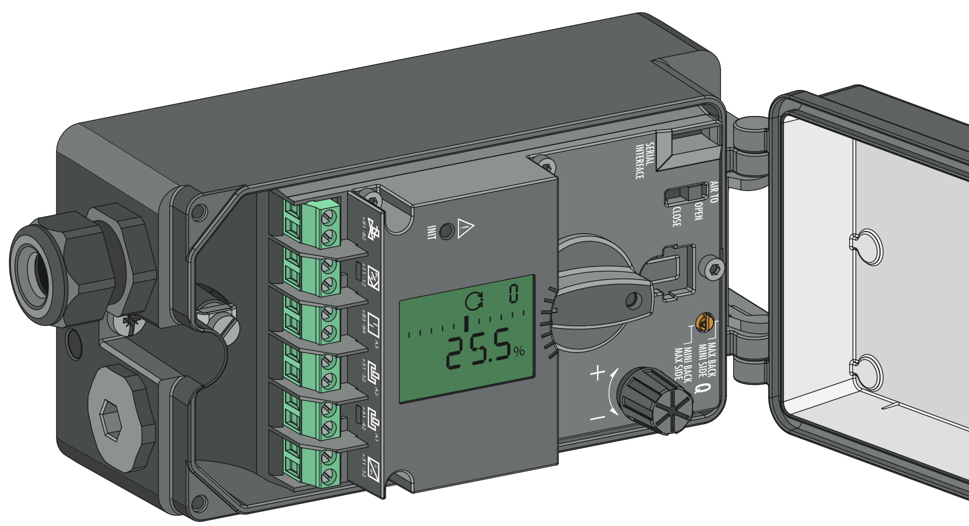
SAMSON

New integrated diagnostics strategy for digital positioners



Special print from
„Industriearmaturen · International Edition“
2004

By:
Dr.-Ing. Jörg Kiesbauer

New integrated diagnostics strategy for digital positioners

J. Kiesbauer, SAMSON AG

Besides actually controlling the valve's position, a digital positioner also provides additional information about its own condition as well as information about the mechanical components such as the valve and actuator. More extensive diagnostic data are obtained by using special diagnostics software with suitable test functions. The plant operator needs to invest time and manpower in training and performing diagnostic tests. It is exactly these resources that are limited in processing plants where it is important to access direct diagnostic information without being inundated by vast amounts of data [1]. The following article proposes a new kind of graded diagnostic strategy which involves the data being collected online in the positioner and being evaluated to create on-board status messages. Explicit messages appear in the process management system sorted in traffic-light coding and classified for the attention of either the plant operator or maintenance technician.

Control valves, digital positioner, on-board failure diagnosis, on-board maintenance information, status messages with traffic-light coding.

Neues integriertes Diagnosekonzept bei digitalen Stellungsreglern

Digitale Stellungsregler bieten neben der eigentlichen Regelung der Ventilstellung eines Stellgerätes auch zusätzliche Informationen über ihren eigenen Zustand einschließlich der mechanischen Komponenten wie Ventil und Antrieb. Weitergehende Diagnosemeldungen erhält man durch spezielle Diagnoseprogramme mit geeigneten Testfunktionen. Das erfordert vom Anwender Zeit und Personal für die Einarbeitung und die Durchführung von Diagnosetests. In verfahrenstechnischen Anlagen sind gerade diese Resourcen knapp und man ist dort an direkten Diagnoseinformationen ohne Datenflut interessiert [1]. Der folgende Beitrag stellt hierzu ein neuartiges, abgestuftes Diagnosekonzept vor, bei dem im Stellungsregler on-line Daten gesammelt und so ausgewertet werden, dass daraus on-board-Statusmeldungen erzeugt werden. Klare Meldungen erscheinen im Prozessleitsystem ampelkodiert und differenziert für Anlagenfahrer und Instandhalter.

Stellgeräte, digitaler Stellungsregler, on-board-Fehlerdiagnose, on-board-Wartungsinformation, Statusmeldungen mit Ampelkodierung

1. Positioner features

The most important task of a positioner is still to move the valve to the desired position as quickly and exactly as possible in response to commands given by the process control system. Analog positioners have always been capable of doing exactly this, but they are not as convenient as digital positioners which provide an automatic initialization routine and numerous settings. But due to the restricted clock cycle of the integrated microprocessor, the digital control algorithms lack the dynamics of their analog counterparts.

The best approach is to use a combination of digital and analog components for signal processing before feeding the signal to the positioner's air output booster. In such positioners, the set point W is recorded at entry stage (Figure 1), which can be done in several ways. With a 4-20 mA two-wire system in automatic mode, the set point is issued as a 4-20 mA signal by the process control system and digitized by the A/D converter (4). In manual mode, the conversion of the set point into a digital signal is facilitated by the rotary pushbutton and display (16), the serial interface or the superimposed HART signal (FSK, 17). In a fieldbus system, the input signal in automatic mode is always digital right from the start.

The internal PD controller (3) uses the digital set point W and the analog valve travel signal X provided by the distance sensor (2) as feedback to create the internal drive signal Y, which is required to control the i/p module (6) together with the pneumatic booster (7). The booster changes the supply pressure in the actuator by filling and venting it until the desired valve position has been reached. An additional advantage is the very small internal leakage current with the flow regulator (9) because it reduces the influence of the internal

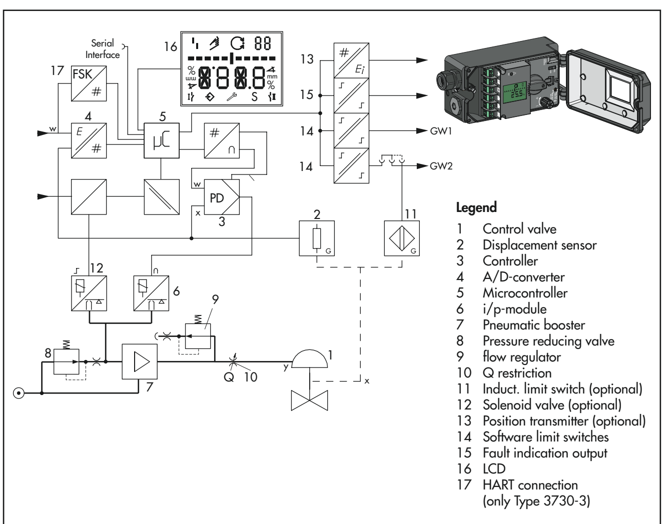


Fig. 1: Schematics of SAMSON Digital Positioner Type 3730-3

hysteresis on the positioner. In addition, the pneumatic components are constantly purged with air, which increases positioner reliability.

The control parameters of the PD controller can be set digitally with the help of digital potentiometers. As a result, they can be adapted perfectly to the control valve during the initialization routine.

The PD controller (3) thus operates both with digital (set point, control parameters) and analog components (valve travel, controller itself). This leads to the excellent dynamics of the control loop, as demonstrated by Figures 2 and 3.

In case of sinusoidal input, the positioner follows the input signal with only a very low phase shift even at a frequency of 1 Hz and an amplitude of 5 %. After a certain period of time, the positioner equipped with the switching piezo valves even stops following the sinusoidal set point altogether because the positioner itself increases the required dead band (tolerance band) and no longer responds to small set point changes.

In case of step input with signal changes of 2 %, the positioner responds to the set point without delay or overshooting while other positioners cannot keep up in this case. In addition, two of the other positioners show strong deviations from the travel actually measured at the valve stem due to the inexact mechanical travel transmission and measuring system. The previously described new positioner design even takes into account the kinematic transmission of the actual travel position over the measuring angle of the internal potentiometer to exclude non-linearities from the calculations.

The measurements depicted in Figures 2 and 3 were performed right after the automatic initialization routine had been completed. The new SAMSON Type 3730 Positioner is initialized at the push of a button, immediately operating with the highest level of precision. The Type 3780 Positioner also produces very good results, although it responds less dynamically due to its design with two solenoid valves. The other positioners, however, need fine-tuning, which might take a few minutes. Today, operators do not have enough time to do that. They expect a positioner to be initialized at the push of a button.

An added advantage is the positioner's emergency operating mode that takes over when the distance sensor fails. The fault-tolerant positioner continues operation, using the previously determined correlation between the internal drive signal Y and the set point W; the desired valve position is almost achieved.

The signals issued by the distance sensor X (item 2 in Fig. 1) and the internal drive signal Y are also digitized, making them

Special print from "Industriearmaturen · International Edition" 2004

accessible isocyclically in the microprocessor or memory. When analyzed intelligently, the signals X, W, and Y provide an extensive amount of information about the status of the positioner, actuator, and control valve.

2. Diagnostic methods and online raw data

2.1 Standard diagnostics

During automatic initialization as well as during normal operation of the positioner, a whole lot of information is collected and possible sources of fault can be detected. The list in Figure 4 illustrates the available data points.

The Status section lists information about the operating time of the positioner. The information specifies both how long the positioner has been switched on overall and how long it has been operating in its permissible range without resting in closed position. The information is based on two points in time: the very first and the last initialization routine. The number of zero calibrations, initialization routines, and configuration changes performed indicates whether the control valve assembly frequently required maintenance or modifications. Naturally, it is also displayed whether the positioner has yet been initialized at all.

A fault in the positioner is indicated as a high priority status when, for example, an operating or hardware fault was detected.

If fail-safe action was triggered, "Failsafe position" status is signalized. It is also indicated whether the fail-safe action was triggered by the optionally integrated solenoid valve.

As the positioner can also be operated locally using its controls, it is visible from the control room whether work is currently being performed on the positioner in the field.

Faults occurring during the automatic initialization routine are indicated as Initialization errors. Codes 50 to 52 in Fig. 4, for example, show that there is a fault either in the mechanical attachment or in the parameters adjusted for the rated travel or the travel transmission lever. Important information is also provided by the Operating errors.

The "Control loop fault" message is displayed when the control valve no longer reacts to the controlled variable within the permissible response times.

If the zero point shifts by more than ±5 % (default setting that can be modified by the operator), the "Zero shift" message is indicated. Such a fault can occur when the mounting position of the positioner is subsequently changed, when the valve trim is worn or when there are deposits between the seat and plug.

"Autocorrection" indicates a fault in the data section of the positioner that was detected and corrected by the selfmonitoring function.

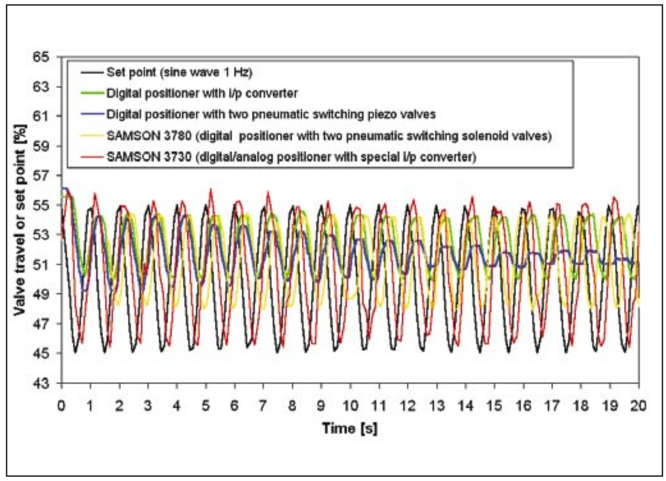


Fig. 2: Response of different positioners to sinusoidal input

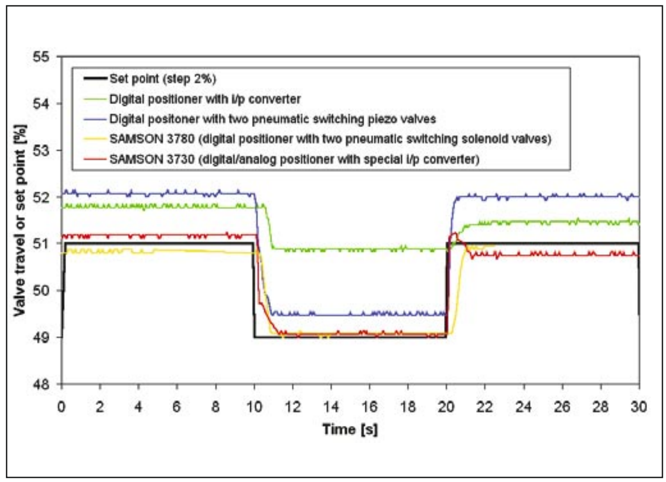


Fig. 3: Response of different positioners to step input

A "Fatal error" suggests a fault in the safety-relevant data that cannot be corrected by the positioner's autocorrection feature. A possible cause may be EMC interference. To correct a fatal error, the positioner must be reset and initialized again.

If the current supply (approx. 3.7 mA for HART) is insufficient, "W too small" is indicated. In addition, the operator can specify a limit for the total travel performed since the last initialization. If the positioner's total valve travel exceeds this limit, "Total valve travel exceeded" is signalized.

An additional warning is issued when the operating temperature of the positioner measured by an on-board temperature sensor exceeds the permissible range. Moreover, the positioner records the maximum and minimum operating temperatures that occurred as well as how long the limits were exceeded.

Critical faults also include Hardware errors. In case the unit measuring the valve travel X fails, an "X-signal fault" is displayed. Nevertheless, the positioner continues operation in

Name		Value	Unit	Comment
Status				
Switched-on device		1879	h	
Device in control		1584	h	
Switched-on device since initialization		867	h	
Device in control since initialization		569	h	
Error occured (fault alarm output)		Yes		
Status solenoid valve		Not implemented		
Fail safe position		Air to close		
Device initialized		Yes		
Start with default values executed		No		
Local operation active		No		
Configuration changed flag		Yes		
Number of zero point adjustments		0		
Status limit switches				
x falls below A1		No		
Status limit switch A1		Non conducting		
x exceeds A2		No		
Status limit switch A2		Non conducting		
Initialization errors				
x > range		No		Code 50
Delta x < range		No		Code 51
Attachment		No		Code 52
Initialization time exceeded		No		Code 53
Initialization / solenoid valve		No		Code 54
Travel time too short		No		Code 55
Pin position		No		Code 56
No emergency mode		No		Code 76
Operating errors				
Control loop		Yes		Code 57
Zero point		No		Code 58
Autocorrection		Yes		Code 59
Fatal error		No		Code 60
W too small		No		Code 63
Total valve travel exceeded		No		
Exceeded allowed temperature range		No		
Hardware errors				
x-signal		No		Code 62
i/p-converter		No		Code 64
Hardware		No		Code 65
Data memory		No		Code 66
Control calculation		No		Code 67
Program load error		No		Code 77
Data errors				
Control parameter		No		Code 68
Poti parameter		No		Code 69
Adjustment parameter		No		Code 70
General parameter		No		Code 71
Internal device error 1		No		Code 73
HART parameter		No		Code 74
Info parameter		Yes		Code 75

Fig. 4: Standard diagnostic messages (SAMSON Positioner Type 3730 EXPERT)

emergency mode, but needs to be replaced as soon as possible. Further faults include "i/p converter fault" (power supply circuit ofi/p converter interrupted), "Hardware error", "Data memory fault" (writing to data memory no longer possible, e.g. when there is a deviation between written and read data), and "Control calculation fault" (hardware controller (item 3 in Fig. 1) is monitored by control calculations).
In case faults occur in the memory data, a Data error is signalized. For example, parameter faults can be caused by EMC interference; such faults are then issued as Control parameters.
Several of these fault parameters are also indicated locally on the positioner display (Figure 5).

2.2 Advanced diagnostics without additional sensors

The standard diagnostic information mainly focuses on the positioner itself. Advanced diagnostics also include status messages about the actuator, control valve, and the air supply as the signals X, W, and Y are more thoroughly analyzed.
The positioner requires raw data for this. During operation, the positioner monitors the specified signals and analyzes them with the help of the integrated microprocessor. The processor's only task is to supply the analog controller with the set point W at certain intervals. Thanks to the microprocessor not being involved in the control process, it can perform the following online analyses:
• Data logger

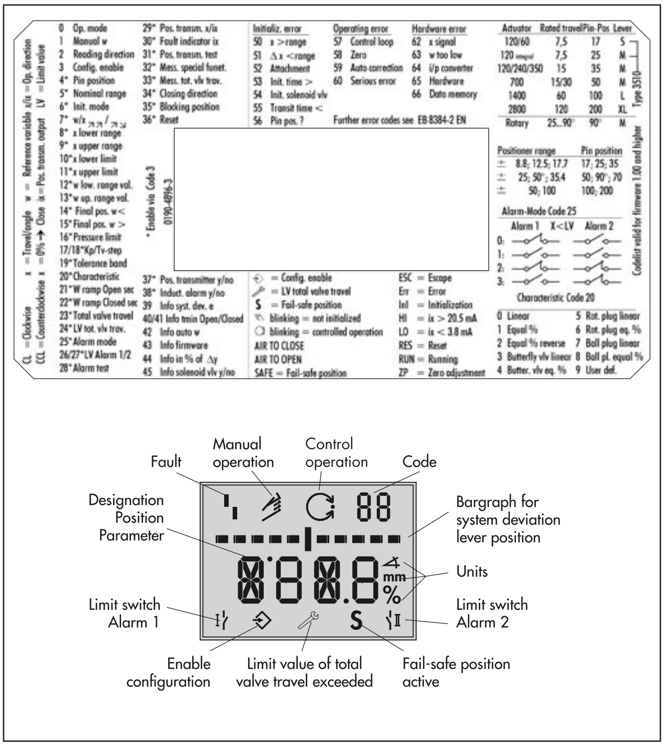


Fig. 5: Standard diagnostic codes on the display (SAMSON Positioner Type 3730)

- Histograms for system deviation E, valve travel X, and cycle counter depending on the amplitude
- Final position trending (zero point)
- Valve signature diagram plotting drive signal Y versus valve travel X

In the Data logger, a distinction is made between permanent and triggered operation.

In permanent operation, the values of the valve travel X, system deviation E, set point W, drive signal Y, and time t are written to a FIFO (first in, first out) memory at a sampling rate that can be set by the operator. As a result, the positioner always has the latest values that can be used to visualize the performance.

In triggered operation, no values are written to the FIFO memory before the trigger condition is met. The data logger can be triggered either by the optionally integrated solenoid valve or an adjustable trigger threshold for the valve travel (e. g. "set point W > 1 %" when the valve is closed). Data logging always includes a few values recorded before the trigger condition is fulfilled.

In any case, the data logger – when triggered by the solenoid valve – can be used to check the proper functioning of the solenoid valve in safety valves as well as to find out whether the valve canbe actuated at all (ESD = Emergency Shut Down).

In the Histograms, the monitored variables are assigned to certain classes, e.g. the range of the valve travel X is arranged in classes of 5 %. The values are recorded online at certain intervals. Each time the requirements for a class are met, its counter is incremented by 1. Each class counter is referenced to the overall counter and saved in percent. As a result, the valve position can be expressed in percent (Figure 6). All histograms differentiate between long-term and short-term values (since the first initialization and the latest point in time).

Such statistic analyses provide very important information. A histogram for the valve travel X, for example, specifies the main operating range of the control valve over its life cycle and indicates recent trends, pinpointing a shift in the operating range. The cycle counter includes information about the dynamic stress that the bellows or packing are exposed to.

If the control valve closes frequently (e. g. in batch processes), the zero point can be logged. The „Final position trending" function may indicate whether the zero point shifts gradually due to wear acting on the seat and plug or whether the zero point alternates in travel transmission due to backlash.

The Valve signature diagram plotting drive signal Y versus valve travel X is based on the drive signal Y as the internal control signal value of the i/p converter. Depending on the valve position, this signal is almost linear, similar to the supply pressure in a pneumatic actuator. This curve is measured during automatic initialization and saved as a reference in the positioner (Figure 7).

The pressure drop across the control valve causes the supply pressure in the actuator at the same valve travel to changed because the flow forces disturb the force equilibrium established at the valve stem.

A similar effect occurs when the actuator springs are relieved of their pretension due to the failure of one or more springs. As a result, the relation between internal drive signal Y and valve travel X is changed. For a control valve with failsafe action "fail-to-close", Y is shifted downward, at the same time reducing the gradient. The pressure drop across the control valve during operation, however, also causes Y to drop, but the gradient is increased and becomes dependent on the valve travel.

In case significant leakage occurs in the pneumatic system due to leaking screw glands or a ruptured diaphragm, the control signal starts to increase continuously from a certain valve travel onward compared to the reference curve.

If the supply pressure of the positioner no longer suffices, the drive signal Y starts to increase almost unsteadily from the restricted valve travel onward.

During online operation, the positioner constantly records the drive signal Y in relation to the travel and calculates the mean

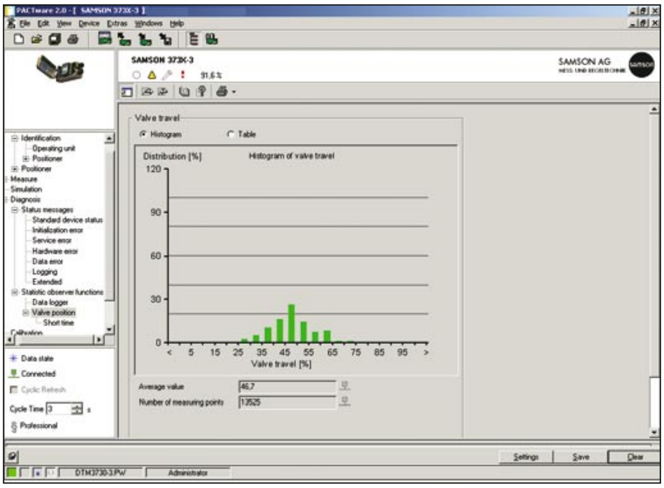


Fig. 6: Online histogram function (valve travel) in SAMSON Positioner Type 3730 EXPERT+

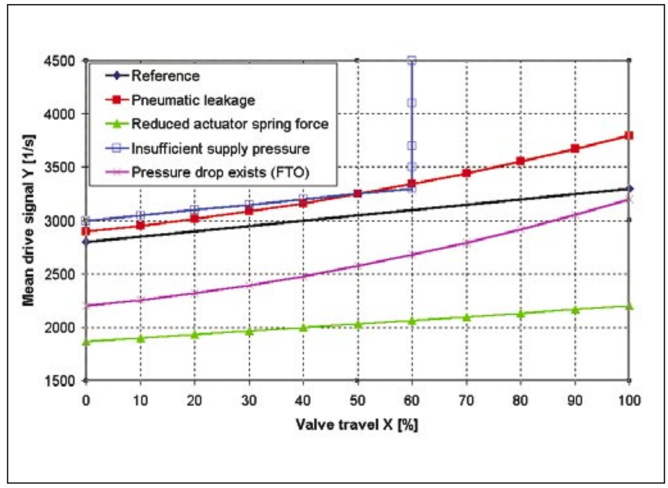


Fig. 7: Valve signature diagram plotting drive signal Y versus valve travel X based on data in SAMSON Positioner Type 3730 EXPERT+

value (depending on the valve travel) including variance without disturbing the process. The mean value is reset with each initialization.

In addition, recent data are analyzed in the same way to detect short-term changes.

In a control valve with fail-safe action "fail-to-close" and direction of flow "flow-to-open" through the valve, the long-term mean value over the entire travel range will be located below the reference curve, similar to the differential pressure curve in Fig. 7.

However, if the mean values are increasingly located above the reference curve, this indicates an imminent pressure problem, i. e. a supply pressure change or a pneumatic leakage in the actuator-positioner system.

In case the mean values fall below the reference curve while the gradient decreases as well, the reason may be that the springs are losing their compression force.

This information obviously relies on the travel range that the valve has actually passed through.

In offline operation and with the plant shut down, e.g. when maintenance work is scheduled (i.e. without pressure drop across the plant), the valve can move through the entire travel range using the active test function to check the information gathered during online operation.

A change in friction forces can be detected with the help of the Hysteresis test. In standard online operating mode, the positioner constantly monitors how the set point W changes. If the set point changes within a tolerance band to be specified by the operator (e.g. 1 %), a lower-level hysteresis test can be started. During this test, the valve position is changed in a ramp-like way (Fig. 8a). The drive signal Y and the change of the valve travel X are analyzed regarding the change of $\Delta Y_{Friction}$ for changes in direction. As is illustrated in Figures 8a and 8b, $\Delta Y_{Friction}$ increases as the friction increases.

To prevent the process from being disturbed constantly, the operator can specify the minimum interval to be observed between the tests (e. g. twice per day). The test is cancelled immediately and the positioner resumes standard online operation when the set point exceeds the tolerance band. All recorded values for

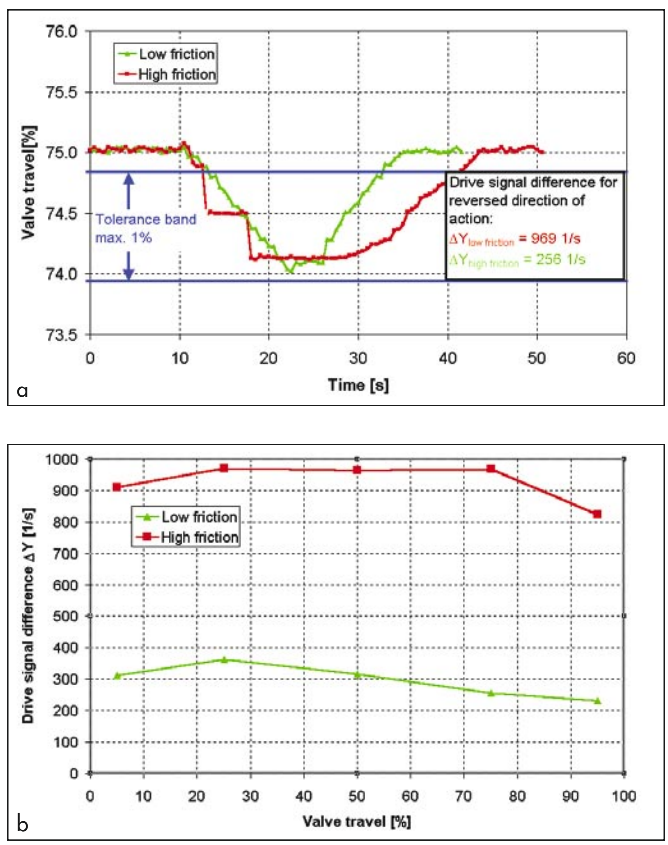


Fig. 8: Hysteresis test (friction detection) in SAMSON Positioner Type 3730 EXPERT+

$\Delta Y_{Friction}$ are assigned to the respective valve travel range. In this case, too, the mean value is calculated for all values recorded since the last initialization. Nevertheless, values are also recorded over the short term to detect short-term changes.
Naturally, the valve can be moved to defined positions over the entire travel range in offline operation also when the plant is shut down. In addition, $\Delta Y_{Friction}$ can be determined for each data point. This is done in addition to the offline signature test described above (valve signature diagram plotting drive signal Y versus valve travel X).
Further test functions include the static characteristic (deadband andhysteresis) and the step response with an analysis according to the ENTECH standard.
Based on this set of raw data, the entire control valve can be analyzed in the positioner itself with a diagnostic software tool. The analysis provides clear status messages with recommendations for maintenance and servicing as illustrated in Figure 9.
A further advantage is that no additional sensors (e. g. a pressure sensor to measure the supply pressure in the actuator) are required [2].

2.3 Advanced diagnostics with additional sensors

For certain applications, the operator wants to know the internal or external leakage rates. Only indirect statements can be made using the diagnostic methods described in the above section as well as the methods involving signal pressure measurement.
Direct statements require the use of additional sensors.
Therefore, the positioner presented in this article is equipped with a binary input. Optionally, a pressure switch can be used to detect leaking stem seals. This switch is activated when the medium leaking from the stem seal creates a pressure in the control volume between the primary and secondary seals. If this happens, the „External leakage" parameter in Fig. 9 is explicitly set to „exists".
Alternatively, the positioner can be equipped with a sensor for structureborne sound with integrated electronics for analysis, which can detect an increased leakage rate between the plug and seat or between the seat and body. The sensor electronics are fully integrated into the positioner electronics.
Electrical power is supplied by the power supply of the positioner.
Each time the valve closes (Tightclosing function), the intensity of the signal is measured. The signal's intensity as well as its change over time are included in the diagnostics.
Non-automated systems are used on the market for special applications that allow maintenance technicians to detect the internal leakage directly on site when the valve is closed. However, they are not integrated solutions.

The applied structure-borne sound sensor detects internal leakage of approximately 0.15 % of the maximum flow rate. The sensor does not check the leakage class but indicates significant leakage rates between flow rates corresponding to leakage class and rangeability. The analyzed signal ranges are not disturbed by extraneous noise. The sensor is best mounted on the valve bonnet (NAMUR rib).

3. Integration into process control systems

The positioner presented in this article is capable of performing real on-board diagnostics with a graded strategy. The vast amount of raw data is analyzed in the positioner in the form of status messages.
As a result, integration into different process control systems is greatly facilitated. The operators no longer have to activate test functions. Depending on the aspects they are interested in, clear messages for either plant operators or maintenance technicians are displayed. Depending on the applied control system, these messages can also be color coded similar to traffic lights (green, yellow, orange, and red). The positioner reserves one configurable "color byte" for each status message. Moreover, up to 30 of the last generated status messages and actions are logged with the respective operating hour they occurred in.

- Green: OK
- Yellow: maintenance required (wear tolerance will be exhausted in the medium term or faster than expected)
- Orange: maintenance indispensable (wear tolerance will soon be exhausted)
- Red: failure (wear tolerance exhausted)

All parameters for these diagnostics can be read and written using HART commands or DD (Device Description) files. The same obviously applies to other communication methods including FOUNDATION Fieldbus and PROFIBUSPA.

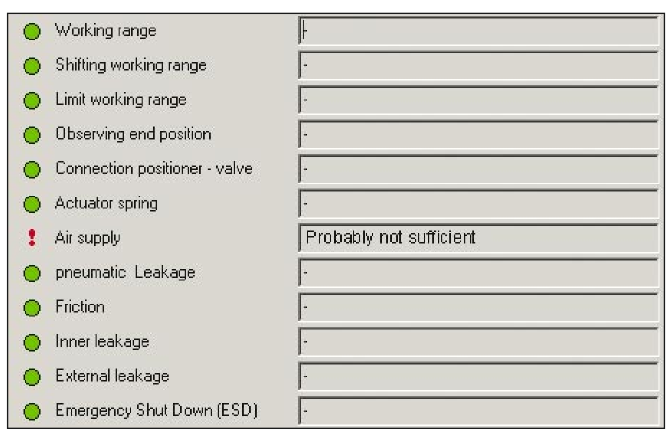


Fig. 9: Advanced diagnostic status messages (SAMSON Positioner Type 3730 EXPERT+)

As a result, all data points can be accessed using various process control systems and engineering tools, with the restriction that graphical representations (e.g. histograms) cannot be generated in all systems.
In such cases, a DTM (Device Type Manager) represents a more suitable solution. DTMs are more and more often integrated into process control systems as they enable the manufacturers to visualize the features of their devices according to their own wishes (Figure 10).

4. Remote maintenance and diagnostics

These new structures and strategies are best suited to perform real remote diagnostics. The fact that status messages are available enables operators to gather information from the positioner without actually influencing it.
The manufacturer provides a centralized server for remote valve diagnostics with an operating and monitoring tool (e. g. SAMSON's TROVIS-VIEW software). Staff at the customer's or at an engineering and sales office can establish a connection between their PC and the server using a modem, ISDN, DSL or a leased line. Meanwhile, they connect to the control valve on site over TROVISVIEW. A service or R&D technician is at the "other end" of the line at the manufacturer'sand reads data about the remote control valve from the server using TROVIS-VIEW; even remote operation is possible. Typically, both participants will also exchange information over the phone while performing remote maintenance or diagnostics.
As a result, the manufacturer can read diagnostic information directly from the device and the after-sales service technicians can give immediate recommendations for the control valve or positioner without having to send a technician to the customer's site or the engineering and sales office. Even operating faults can be corrected right away, sparing service technicians unnecessary trips because of minimal errors. Further visual information directly from the site can be supplied by installing a web cam. An additional benefit is that the most important valve and actuator data are saved in the positioner.

5. Conclusion

The positioner presented in this article is equipped with onboard diagnostics and fully integrated diagnostic features that are capable of generating online diagnostic and status messages. These messages can be read and visualized by any process control system over DDs or DTMs. They can be displayed differently for plant operators and maintenance technicians. This feature complies with the NAMUR recommendation on diagnostics for Fieldbus devices that is currently in preparation. The raw data that are collected over the life cycle of the

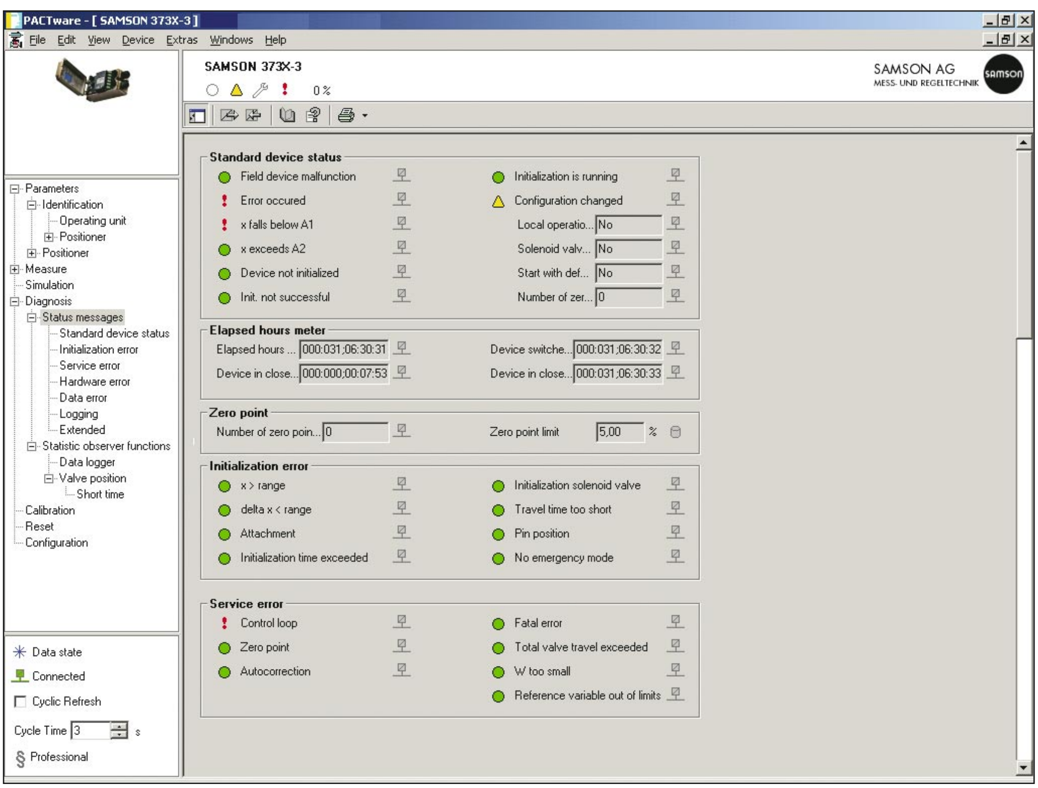


Fig. 10: Device Type Manager (DTM) for SAMSON Digital Positioner Type 3730-3

control valve and that the diagnostics are based on (e.g. histograms) play an important role. They supply the manufacturer's technicians with data reaching far beyond status messages, giving useful information about the use of the control valve and finally enabling them to provide a better and more thorough after-sales service, e.g. by supplying Internet connections for remote maintenance.

References

[1] Kiesbauer, J., Hoffmann, H.: Online Plant Asset Management in Control Valves. Valve World Magazine Vol. 8 August 2003, p. 55-65.

[2] Kiesbauer, J.; Diagnosetools bei Stellgeräten [Diagnostic Tools for Control Valves]. atp – Automatisierungstechnische Praxis 42 (2000), Vol. 3, p. 38-45.

Dr.-Ing. Jörg Kiesbauer is head of the Development Test Department at SAMSON AG, Mess- und Regeltechnik, Frankfurt/Main, Germany. Main fields of work: R&D in the field of control valves including electric and pneumatic accessories and self-operated regulators (flow capacity, sound emission, failure diagnostics, optimization of prediction methods). Since 1999, he has been a guest expert of IEC Working Group 65B-WG9 and in the DKE 963.

Phone: +49 69 4009-1464, Fax: +49 69 4009-920

E-mail: drjkiesbauer@samson.de

SAMSON AG · MESS- UND REGELTECHNIK · Weismüllerstraße 3 · 60314 Frankfurt am Main · Germany
Phone: +49 69 4009-0 · Fax: +49 69 4009-1507 · E-mail: samson@samson.de · Internet: http://www.samson.de

2004-05 HD · WA 136 EN