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Online Plant Asset Management in control valves

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Modern software-based asset management systems (AMS) are being increasingly used in the chemical industry to maximize efficiency and performance of all the processes in a chemical plant. The area of Online Plant Asset Management systems (aAMS) involves all the activities and procedures required to maintain and increase the value of a plant. Special attention is paid here to field devices, in particular to control valves considered to be the "workhorses" of the process as they are required to function reliably over long periods of time at high load. Control valves with smart positioners fit into the concept of aAMS very well as they can monitor themselves and capture important information for the plant operator as well as the maintenance technician. Operators of new plants are using such modern control valves to a greater extent, but the additional "smart" features are only being made use of hesitantly or, in some cases, not at all. The manufacturers themselves get the impression that this subject is often a point of discussion, but its actual application is restrained. This article attempts to take stock of the subject concerning failure diagnosis and early fault recognition in control valves and to encourage users to make better use of current possibilities. In addition, the article highlights future development potential to improve the reliability and integration of information gained about the valve condition.

Anlagennahes Asset Management bei Stellgeräten – Eine Standortbestimmung

Moderne Asset Management Systeme (AMS) auf Softwarebasis kommen heute in der chemischen Industrie zur wirtschaftlichen und technischen Optimierung aller Prozesse einer chemischen Anlage zunehmend zum Einsatz. Der Teilbereich des anlagennahen Asset Management Systems (aAMS) beinhaltet alle Tätigkeiten und Massnahmen zur Erhaltung und Steigerung des Wertes einer Anlage. Ein besonderes Augenmerk liegt hier auf den Feldgeräten, speziell den Stellgeräten, welche quasi als „Arbeitspferde" im Prozess bei hoher Belastung lange zuverlässig funktionieren müssen.
Stellgeräte mit digitalen, kommunikationsfähigen Stellungsreglern passen gut in das Konzept des aAMS, da sie sich selbst überwachen und wichtige Informationen für die Anlagenfahrer und Instandhalter geben können. Zwar setzen die Anwender in Neuanlagen zunehmend solche modernen Stellgeräte ein, nutzen aber die zusätzlichen „intelligenten" Eigenschaften nur zögerlich oder gar nicht. Als Hersteller gewinnt man den Eindruck, dass alle über dieses Thema diskutieren, sich aber beim praktischen Einsatz zurückhalten. Dieser Beitrag versucht, eine Bestandsaufnahme zum Thema „Fehlerdiagnose und Fehlerfrüherkennung bei Stellgeräten" zu machen und dabei die Anwender zu ermutigen, die heutigen Möglichkeiten intensiver zu nutzen und Erfahrungen zu sammeln. Natürlich werden auch zukünftige Entwicklungsmöglichkeiten aufgezeigt, die noch zuverlässigere und besser integrierte Zustandsinformationen erlauben.

1. Introduction

The term "Online Plant Asset Management" (aAMS) is described in detail in the NAMUR recommendation NE 91 [1]. This recommendation refers to the asset management system (AMS) as a data processing system which supports Online Plant Asset Management (aAMS). The main objective of an AMS is to provide online information for the technical evaluation of plant components. It allows access to technical plant documentation and business administration systems.

While the process control system supports the plant operator in running the process, the aAMS, which functions similar to a plant control system, supervises the technical operation in the following areas:

- Assessment of the condition of plant components
- Decision about action that needs to be taken
- Preparation and execution of the action in the plant.

The functions and access to information include:

- The aAMS makes primary condition information accessible, no matter where it is generated.
- It compresses primary condition information or it forwards the results of the relevant data processing. Primary condition information especially for field devices includes:
- Alerts issued for device failure, maintenance check request or function check,
- Maintenance check request generated from process variables and basic calibration data,
- Status information with online messages to the AMS
- Monitoring of trends and statistics to facilitate error diagnosis and weakness analysis
- Special diagnosis using manufacturer-specific modules which are integrated into an aAMS.

In any discussion involving status recognition, it should be taken into account that asset management starts well before a control valve is purchased, i.e. sizing and selecting the correct control valve. An actual case in a German refinery is described in [2] where a rotary plug valve was used in operating ranges which it was simply not designed for (excessive outlet velocities in a two-phase flow). The outcome was two plant shutdowns within approximately two years and cost of ownership amounting to around EUR 400,000. In the meantime, a larger globe valve has been installed in the plant and works perfectly well. Even though its initial purchase costs were higher, the total costs spread over two years amount just to EUR 50,000.

It is therefore better to proceed bearing in mind that only until control valves have been chosen and sized to match the application properly that it is really worth using smart devices.

2. Current fault and condition monitoring using digital positioners

The primary condition information mentioned in the introduction of this article is gathered by digital positioners mounted to control valves [3,4]. These positioners function using digital signals and algorithms to control how far the valve is to be opened or closed according to current set points. Additionally, they recognize the entire condition of the valve and any faults that may occur.

Table 1: Summary of signals used in digital positioners

Signal	HART	PROFIBUS-PA	FOUNDATION FIELDBUS
Time t	X	X	X
Valve position x	X	X	X
Set point for valve position W_x	X	X	X
Internal control signal Y	X	X	X
Process variable P			(X)
Additional binary sensor S	Option	Option	Option
Additional analog sensor S	Option	Option	Option

Table 1 summarizes which signals are currently available depending on the type of communication (HART, Foundation-Fieldbus, Profibus-PA) that the positioner uses. The first four signals listed are essential to actually position the valve. They already contain a great deal of information that can be used to recognize the condition, or in some cases, changes in condition, provided this information is analyzed intelligently [4, 5]. Concerning Foundation Fieldbus communication, additional information can be gained by using the PID control loop for process variables such as pressure, flow rate, temperature etc., which can be used for diagnostic purposes as well. It all depends on the manufacturer's train of thought to whether sensors that are not absolutely essential for positioning the valve are provided as an option (see section 2.3) with the intention of integrating extended or more detailed methods to detect faults. These sensors issue binary or continuous signals.

What benefits does aAMS have?

2.1 Automatic commissioning

The automatic commissioning after the positioner has been mounted to the valve involves determining the mechanical travel limits (zero to maximum travel) and the automatic tuning of the best positioner setting (control quality and control dynamics). Numerous manufacturers use tuning kits (PD), which can be loaded into the positioner by the user over an engineering tool, for example, AMS (EMERSON) or PDM (SIEMENS) or using an on-site setting (SIEMENS SIPART, SAMSON 3730,

Fig. 1: SAMSON 3730 Positioner with on-site operation

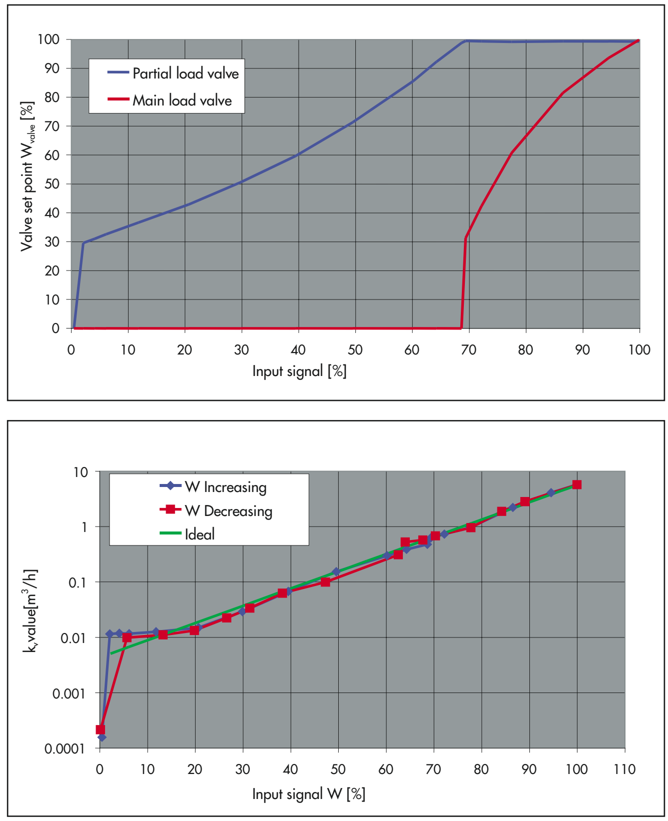

Fig. 2a,b: Split-range control with a digital positioner (a: non-linear characteristic for both valves; b: total k_v characteristic)

Fig. 1). Several positioners available on the market also feature a permanent online adaptation to the current operating conditions [3,4]. In all cases, the data sets can be stored in the engineering tool and loaded onto a replacement positioner, if need be, once they have been optimized. These features provide major benefits during commissioning and servicing the plant. The service technician is confronted with a problem with bus systems if a process control system does not exist. In this case, it is useful when positioners additionally have a serial interface over which the positioner can be prepared separately for use in a process control system (e.g. SAMSON FF or PROFIBUS-PA positioner with SSP interface and TROVIS-VIEW [7]).

2.2 Additional functions

A digital positioner offers, in addition to the functions that are available in conventional analog positioners, other interesting features:

- Defined tight-closing function
- Non-linear relation between the set point and the required valve position
- Defined operating range for the valve opening

An example serves to illustrate these additional functions:
In a refinery, two control valves in a parallel arrangement work with analog positioners to inject cooling water. The originally planned split-range control does not meet the high demands placed on control quality especially during the start-up phase. Consequently, the plant operator had to intervene in the process manually during the start-up procedure, which meant the large valve was operated to a great extent in the closing range and failed after a short time due to cavitation wear.

This problem can be prevented by using two control valves equipped with digital positioners: Angle valves can still be used as before, designed with the process medium in a flow-to-close direction. Moreover, the minimum valve opening in the control range must be approx. 30% in relation to the standard nominal travel. This helps to protect the seating surface against wear for small flow rates and at high pressure drops of approx. 130 bar. The characteristic curves are equal percentage. On plant start-up, the large valve does not open with a minimum of 30% before the small valve opening has reached approx. 99%. By setting the characteristic curves (Fig. 2a) beforehand, an almost equal percentage characteristic over the entire k_v curve can be achieved with a rangeability of approx. 1000:1 (Fig. 2b). When the valves are closed, the tight-closing function by explicit activation for input signals < 1% or < 30% ensures that the maximum actuator closing force is applied by venting the actuator completely. This serves to strongly reduce high creeping leakage rates which would otherwise cause wear at the seating surface of the valve plug.

2.3 Standard condition data (status values)

During automatic commissioning as mentioned in section 2.1, the entire valve is checked concerning its performance as well as the optimization of its parameters. In case of a fault, messages and alerts are issued which are indicated, for example, on the display of the positioner (Fig. 1) or in the engineering tool (Fig. 3). Even during operation, tests are constantly run and the results are stored in the positioner's memory. Table 2 shows a list of such messages. The following information is listed in the columns of the table:

- Offline or online?: During offline mode, the process is not running or the valve operates unconnected in a bypass of the main pipeline. In online mode, the valve is required at that point in time by the process
- If possible, information about the condition or cause (intended as an aid for maintenance staff)
- Information about the components in the control valve (intended as an aid for maintenance staff)
- Action that is to be taken (intended for maintenance staff).
- Type of alert:
  - Predictive alert is intended as an aid for maintenance staff. The valve's condition has only worsened slightly, but it will probably get worse. The valve still works properly.
  - Maintenance alert is intended as an aid for maintenance staff. The valve's condition has worsened considerably, yet it still works properly, but could fail at any time.
  - Failure alert is intended for plant operators. The valve has failed.

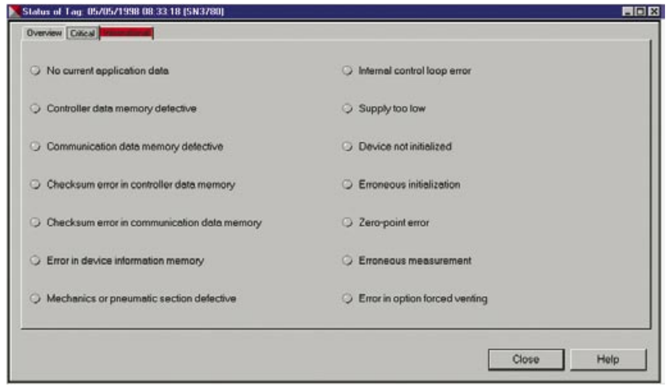

Fig. 3: Alerts and messages in an engineering tool (EMERSON PROCESS MANAGEMENT's AMS) [8,10]

Table 2: Standard status information in digital positioners

Message/Status	Offline or online?	Cause/status	Valve component	Action to be taken	Type of alert
Control loop error	Online	Tolerance band not reached Control lag too high	Positioner Valve Actuator Air supply	Other function checks or maintenance check request	Failure alert
Zero point error	Online (if valve closed) / Offline (commissioning)	Zero point shift	Valve plug/seat (wear/dirt)	Zero point calibration Maintenance check request	Maintenance alert
Electronics	Online, Offline (commissioning)	Data memory defective Controller data memory defective Information memory defective Checksum error in data memory Checksum error in controller Incorrect measurement set point/actual value	Positioner	Exchange positioner	Failure alert
Commissioning	Offline	Erroneous; not completed		Start initialization	Failure alert
Mechanics/ pneumatics	Offline (commissioning)	Supply pressure too low Error in pneumatics/mechanics section Leakage in pneumatics	Air supply Positioner mount. Actuator diaphragm and connections	Maintenance check Function check Check actuator diaphragm and connections, if necessary	Predictive/ maintenance alert
Total valve travel	Online	Limit value exceeded	Stem packing (bellows, packing)	Maintenance check request	Predictive alert
Programmed setting data	Offline (commissioning)	Not available	Positioner	Enter	Failure alert
Status of binary input	Online	Off On	Dependent on sensor, e.g. pressure switch to supervise the conition of the bellows seal	Maintenance check request Replace instrument	Predictive/ maintenance/ failure alert depending on the type of sensor

Table 3: Extended status information in digital positioners						
	Offline or online? depending on method					
Control valve parameters	**Additional pressure sensor**	**Control loop dynamics without additional sensor**	**Statistics**	**Control valve component**	**Action to be taken**	**Type of alarm**
Friction	Offline and online	Offline and online		Packing Deposits on plug/seat or valve stem Pressure balancing seal	Maintenance Remove dirt Maintenance	Predictive alert/ maintenance alert Maintenance alert
Bench set	Offline	Offline		Actuator springs	Readjust/replace springs	Predictive/ maintenance alert
Influence of pressure drop (using the maximum possible actuator force)	Online	Online		Actuator Control valve load	Check sizing/ operating data	Predictive alert
Leakage in the pneumatic unit (actuator chamber, air connections)	Offline	Offline and online		Actuator Connection between positioner and actuator	Replace actuator diaphragm, if necessary	Predictive/ maintenance alert
Supply pressure	Partly offline	Offline and online		Air supply, air supply regulator	Check air supply	Predictive/ maintenance alert
Positioner air filter blocked		Offline and online		Positioner	Check air filter	Predictive/ maintenance alert
Main operating range of the control valve (histogram)			Online		K_{vs} valve larger or smaller	Predictive/ maintenance alert
Simple counter to record change in direction (number or changes in direction without amplitude classification)			Online	Positioner setting		Predictive/ maintenance alert partly
Complex counter to record change in direction (number or changes in direction with amplitude classification)			Online	Dynamic load on metal bellows or stuffing box Positioner setting	Check bellows seal or stuffing box Check control loop parameter	Predictive/ maintenance alert Maintenance alert
Trend on operating range changes (e.g. increasing shift toward smaller valve opening)			Online	Valve plug/seat wear	Check operating data for changes	Predictive/ maintenance alert

2.4 Extended condition data and its analysis

The standard monitoring functions introduced in this article allow the recognition of major valve malfunctions. Table 2 illustrates how difficult it is to pinpoint the direct cause of a fault. The cause is often identified when the process is offline during the commissioning phase rather than online when the process is running. The message "Internal control loop error" in Fig. 3, for example, is a major fault, but its cause cannot necessarily be pinpointed. The maintenance technician therefore does not yet know whether he has to remove the valve from the pipeline or whether he just needs to recalibrate or even replace it.

As a rule, the user has the same requirements as the aAMS (see section 1.):

- Detailed online diagnostic and status messages
- Maintenance information relating to the condition and, where possible, indicating which problem is expected to occur at which point in time and what sort of action should be taken.

Manufacturers of positioners or entire valves are trying to fulfill these requirements in two ways beyond the standard options already available:

- Integrating additional sensors with the main intention of determining the force required by the actuator to move the valve plug against friction and flow forces and to keep it in balance [10].
- Analyzing the positioner signals required to position the valve without the use of additional sensors (the first four sig-

nals listed in Table 1), in particular, their dynamic properties and statistical characteristics [4,5].

In the first method, manufacturers of pneumatically actuated valves that have an actuator with a spring return mostly use a pressure sensor to measure the pressure applied on the actuator diaphragm in relation to the valve position (valve signature as shown in Fig. 4). This corresponds with the continuously functioning additional sensor in Table 1. This method is covered to the most part by the parameters listed in the second column of Table 3. In online operation, reliable statements concerning friction force and pressure applied in the actuator are only possible if the signals in Fig. 4 are recorded during valve operation (hysteresis loop around the current valve position).
In the second method, changes in the dynamic properties of the response signals (valve position X) can be recorded and analyzed in the positioner both offline and online after the reference variable W is changed in small steps (±2%) around the initial valve position (Fig. 5). With the aid of a clear changing pattern table [5] for the delay time t_V and transit time t_L for both moving directions (increasing and decreasing), the initial step is made to detect the parameter changes in the third column of Table 3. These go further than the first procedure. The application of mathematical simulation models also helps to calculate the current status value (e.g. the level of friction force) for certain types of valves.
Additional information arises from the statistical analyses (fourth column in Table 3, [5]).
These days both methods are still implemented in the manufacturers' own software, for example, VALVELINK from EMERSON PROCESS MANAGEMENT [8,10], VALVE MANAGER from METSO [9] or TROVIS-EXPERT [5] from SAMSON, since the special test routines with large amounts of data must be executed and analyzed in the software. The integration into existing engineering tools is still only possible in part and very complicated. This is partly also due to the strong protectionist attitude of system manufacturers who sell their own make of positioner. The FDT concept from PACTWARE with the "printer driver principle" is therefore a promising approach to this problem.
It is not just the diagnostic procedure and parameters that differ considerably, but also the analysis of signal changes or symptoms.
Most manufacturers concentrate on measuring and displaying direct parameters (current parameters or their trend as well) such as friction, pressure applied in the actuator, set point, actual value, dead band. The status analysis of the control valve and its components based on these parameters does not

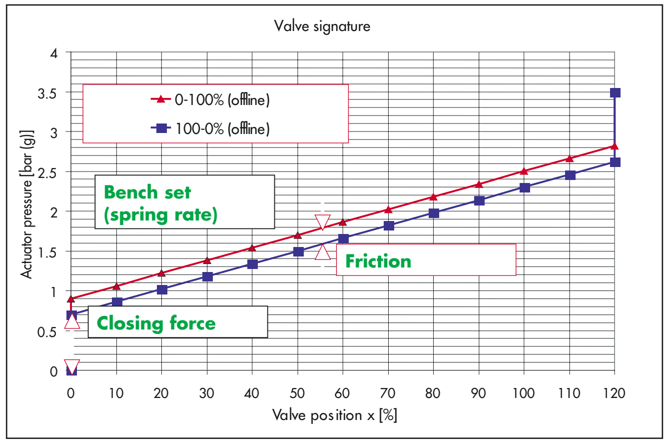

Fig. 4: A typical valve signature plot for a control valve with pneumatic actuator [10]

take place automatically. Some companies [8] provide a diagnostic service at a fee where the recorded test data is analyzed and a report is created. The user is, however, naturally interested in an automatic analysis at no extra charge, as is the case with TROVIS-EXPERT from SAMSON, for example [5].

3. Evaluation of current fault and condition monitoring

As a rule, many manufacturers (in particular, US manufacturers) often give priority to the factor friction in extended diagnostics mentioned in section 2.4. Table 3 shows how friction is determined essentially by the adjustable packing, pressure-balanced seals and, in some cases, dirt in the narrow gaps between the plug and seat, pressure-balancing sleeves or in cage valves. In rotary valves, increased friction in the shaft bearings can additionally occur if a high pressure drop requires a high bearing force at small valve openings. Moreover, piston actuators are often used which themselves have high friction at the piston seals in the actuator. Diaphragm actuators with springs evenly arranged in the actuator, in contrast, have a negligible amount of friction.
Increased friction forces are actually not a real problem, provided the positioner controls the required valve position accurately and quickly. If this is not the case, this condition will be detected with the control loop monitoring function ("internal control loop error", see Table 2/Fig. 3). If the actuator forces or supply pressure are not too low, it is usually due to friction (especially for small signal changes). The user can control this monitoring feature, for example, in SAMSON positioners over the permissible delay time and permissible tolerance band for the remaining system deviation [4]. The authors of this article believe that the full potential of this option is currently not being exhausted by the user. Particularly, in the case of safety valves which normally remain in just the

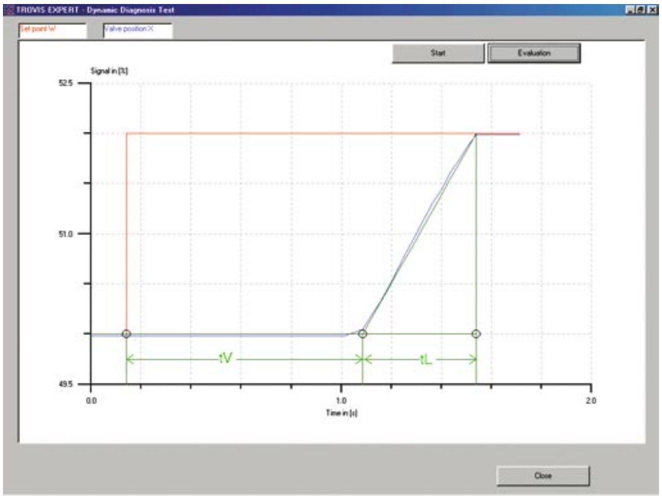

Fig. 5: Analysis of dynamic response signals of the valve position (delay time t_V, transit time t_L) [5]

OPEN or CLOSED position for long periods of time, and must close or open reliably in case of emergency, the possibility to monitor using small signal changes exists when the valves are in their standard position.

It should be mentioned once again at this stage that asset management basically starts when the control valve is selected. Valve designs that work by default at low friction have less problems with friction and therefore do not really need their friction parameters to be directly monitored. If they do increase due to wear, this status change can be recorded with control loop monitoring.
One exception does, however, exist: with regards to the condition of adjustable graphite packings (at high temperatures exceeding 200°C) the drop in friction indicates changes in the compression of the packing (Table 3, second row). The friction is not a suitable indicator in self-adjusting PTFE stem packing (≤ 200°C).
Despite this critical evaluation, the primary condition information listed in section 1 is still important for Online Plant Asset Management and especially for field devices in such a system. The alerts, messages and performance tests listed in sections 2.3 and 2.4 as well as Tables 2 and 3 cover all the major status parameters of control valves. Therefore, the question must be asked why users are still quite hesitant to implement the introduced diagnostic tools. On 30 April 2002, the forum "Intelligent valves for the chemical industry" took place in Frankfurt at the VDMA (German federation for engineering industries) to exchange ideas among valve and sensor manufacturers and end users in the chemical industry. The following conclusions were met:

- Alert messages in Table 2 are undoubtedly important due to the direct status information that they provide.
- Warnings about the extended faults are a step in the right direction, but the use of the manufacturer's own diagnostic tool was found to be inconvenient due to the time spent on training. Additionally, the users were hesitant because of the additional time and effort needed to regularly start the test cycles which is still necessary with this tool.
- In part, the reliability of the diagnostic messages, especially concerning the condition of the packing (external leakage) and the seat and plug (internal leakage) is questioned. The reason for this is that parameters such as friction, closing force or zero point are indirect (and not direct) indicators for these types of leaks.
- Another disadvantage from the users' viewpoint was that the alarm and diagnostic messages differ considerably. Instead, more uniformity linked with clear messages such as "critical", "not yet critical" and "not critical or okay" (traffic light coding) is requested. Furthermore, a distinction should be made between messages for plant operators and maintenance technicians. An option to deactivate these messages should also exist. It was not defined during the discussion whether the deactivation should occur in the device or in the process control system.
- An initial analysis of the diagnostic messages to specify automatic instructions for the maintenance technician is desirable. The actual diagnosis and the decision about what action is to be taken should and must be made by the operator, i.e. a human decision.

4. Future developments

Four areas that need further development arise from the above section.

- The process control software or the engineering software tool must use standardized status and diagnostic terms as well as include standardized interfaces for manufacturer-specific diagnostic tools which, in turn, themselves issue standardized alarms. The methods on how these alarms are to be generated will remain the expertise of the field device manufacturers. This appears to be understandable especially for manufacturers of control valve assemblies made up of valve, actuator and positioner.
- A further major step will be to make diagnostic tools redundant. In their place, diagnostic procedures and tests will run inside the positioner and automatically issue status alarms according to the traffic-light coding system which will then be displayed by the process control system in the appropriate authorization level (standard, expert, administrator). The

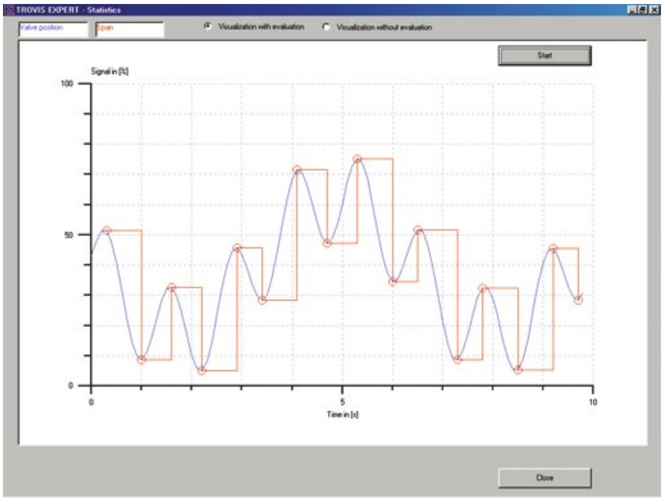

Fig. 6: Analysis of statistical control behavior [5]

maintenance staff are interested in different alarms than the operating staff (e.g. differentiation between predictive, maintenance and failure alerts as listed in Tables 2 and 3).

- The two main sources of error in control valves, i.e. leakage from the packing (external leakage) and between the plug and seat (internal leakage), can still partly be detected using indirect parameters such as friction, closing force or zero point (predictive maintenance information). However, if the user requires reliable, direct statements about leakage, the current state-of-the-art technology still requires the use of additional sensors. Table 3 clearly indicates that the use of additional sensors such as pressure sensors in the actuator is rather pointless as they only recognize changes in the aforementioned indirect parameters. The second method mentioned in section 2.4 that does not use this pressure sensor is much better in comparison.
  - For external leakage, potential solutions include, for example, pressure switches that supervise the pressure in a controlled space between the metal bellows seal and back-up stuffing box or between two stuffing boxes (Fig. 7). These additional binary sensors (Table 1) can be combined with the binary input of a digital positioner which can pass this status (Table 2) as a maintenance alert or as a predictive alert on to a process control system.
  - The article [6] describes a leakage detector for internal leakage and issues a similar binary signal. During the VDMA forum mentioned in this article, users made it clear that they see great potential in this development that is not yet ready for a market launch.
- Moreover, further possibilities arise with Foundation Fieldbus positioners by using PID control loops that can be activated. For example, if the process variable to be controlled involves the valve flow rate, the trend "valve position is shifting closer towards the closing point at a constant flow rate" reveals information about the wear condition of the valve. Statements about the pump upstream of the valve are also possible.

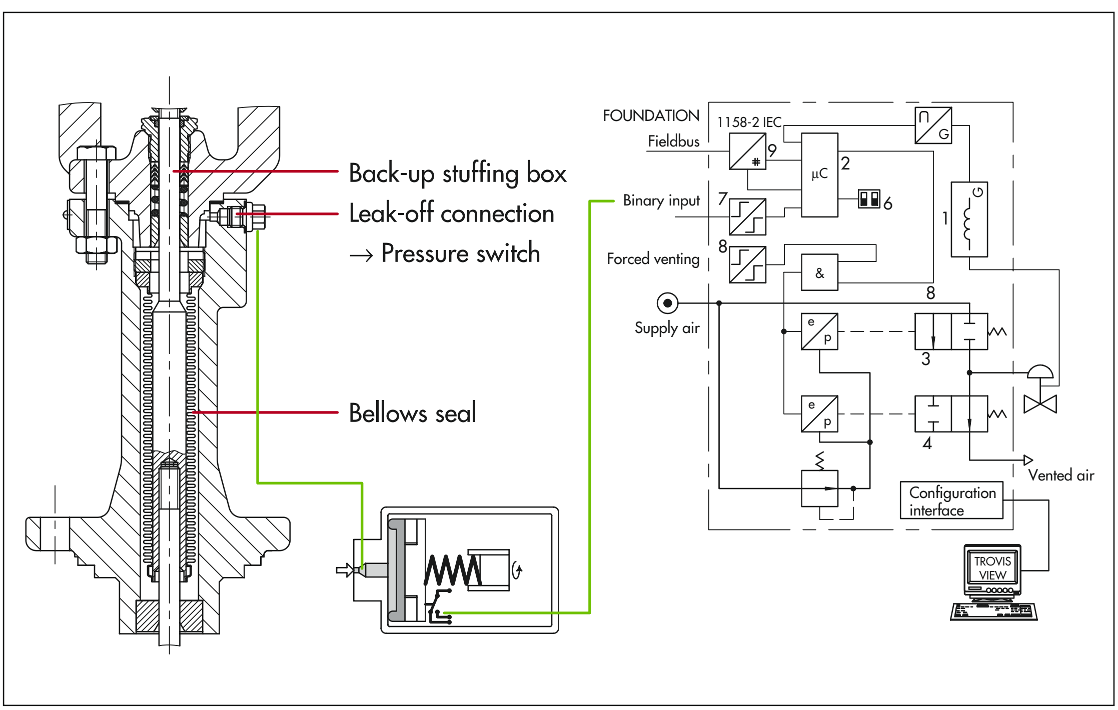

Fig. 7: Supervision of external leakage in valves with metal bellows combined with a digital positioner

5. Conclusion

The standard condition and fault information supplied by digital positioners has been around since these devices were launched, yet the information is still not exploited properly by the users. Particularly, the status alarms "Control loop error" or "Zero point changed" contain valuable information about changes in status (e.g. friction, wear or leakage) during operation. If the user wants a detailed analysis of the control valve's condition, extended diagnostic tools are available which can assist the user in scheduling maintenance work while the valve is running and shortly before any revision work has to be made. The integration of such tools in higher level AMS systems is complicated and only possible under certain conditions due to the different approaches involved concerning interfaces among manufacturers of AMS and control systems. In the long term though, positioners will analyze internal signals much more precisely and allow real-time diagnoses which will be transmitted over modern bus systems to the process control station. Different information will be issued for plant operators and maintenance technicians. As far as critical control valves are concerned, it will also be possible to monitor internal and external leakage reliably and directly. Additionally, the trend will also move towards remote maintenance over the Internet or telephone line. This, however, requires more stringent safety standards to prevent unauthorized or exaggerated interventions in the plant process from the outside.

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