Smart valve positioners and their use in safety instrumented systems

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As part of efforts to reduce life cycle costs of control valves in the process industry, smart electropneumatic positioners play an important role due to their self-adaptive features and their highly developed diagnostic functions. Their use can lead to decisive improvements in availability and reliability. To make full use of this potential, which has often been discussed in theory in the past but hardly been put into practice to date, NAMUR Recommendation 107 and Guideline VDI 2650 provide information on the scope of diagnostics and the generation of alarm states. Applications in safety instrumented systems are of particular interest as smart positioners are used more and more with on/off valves in place of classic solenoid valves. In the process industry, the use of on/off valves in safety instrumented systems is governed by the IEC 61511 standard. The basic principle behind this standard is the safety management life cycle, which can be effectively supported by the diagnostic functions of positioners.

Modern positioners mounted on control valves in the process industry are smart, microprocessor-based instruments. Besides their main task of controlling the valve position, positioners include extensive diagnostics, which have evolved over the years into a fully developed technology.

Diagnostic capabilities

The term "diagnostics" is not clearly defined and comprises various tools and features, which can be classified as follows:

Offline diagnostics: This category includes processes that can only be run during plant shutdown. Typical methods include performing a step response test or stroking the valve over its entire travel range, preferably while logging the set point, actual value and actuator pressure or the drive signal for the positioner pneumatics. In hindsight, these methods were the first diagnostic functions of microprocessor-based positioners.

Online diagnostics: These diagnostic methods can be used while the process is running. The state of the valve is analyzed under actual operating conditions. Furthermore, data are available nearly in real time. However, to avoid disturbing the process, passive monitoring processes can only be used, or at best, only small changes to the valve position can be applied to record the step response. Several major possible functions are listed below [1]:

- Logging and plotting the set point, valve position and actuator pressure. The actuator pressure can either be measured directly or derived from the positioner signals, which is a more elegant solution and avoids additional cost.
- Data logger: Logging the relevant data in the positioner and plotting them over a certain period of time. In this case, intelligent triggering criteria are particularly relevant since the positioner memory is limited.
- Logging and plotting key variables over the entire lifetime of the positioner, for example valve position, set point deviation, travel counter, cycle counter and operating hours counter.
- Zero deviation
- Temperature inside the positioner
- Changes to the set point smaller than 1 %, which allow conclusions to be made on the control performance and the valve friction.

Data processing: The partly extensive data compiled must be summarized. For example, the valve position recorded over the valve lifetime can be displayed well in a histogram. The user has access to raw data, yet data interpretations, such as leakage in the actuator or changed friction, are also provided. These interpretations are calculated using internal algorithms. Guideline VDI 2650 provides a structured list of possible failure modes. NAMUR Recommendation 107 classifies user-defined error messages into various alarm classes. Time-stamped alarms are saved in the positioner.

Table 1: Detectable faults and diagnostic methods

Fault	Reference used by diagnostics
Set point deviation	Directly from the raw data
Valve friction	Step response test, hysteresis test
Valve shut-off impaired (internal leakage)	Zero shift, external ultrasonic sensor
External valve leakage, packing leakage	Packing chamber monitored by external pressure switch, change in valve friction
Packing or bellows wear	Travel counter, cycle counter, change in valve friction
Valve plug wear or damage	Zero shift, change in valve friction around zero point
Actuator spring broken	Pressure/travel characteristic
Unstable control performance	Travel sensor, system deviation histogram
Changed process characteristic	Valve position histogram, cycle counter, cycle counter histogram

Implementation strategy

On-board diagnostics: The first diagnostic methods were implemented on a computer and not in the positioner itself. Now low power consumption and better microprocessor performance make it possible to implement diagnostics in the positioner itself. As a result, online communication between the positioner and a computer while the diagnostics are running is no longer needed. Diagnostics can now be performed continuously, in the ideal case over the whole lifetime of the valve. Similar to an airline's flight recorder, data are recorded continuously and are available in real time or at any selectable time before or after the event to be analyzed.

Intelligent analysis of internal positioner signals means that additional sensors are largely redundant, which reduces cost and technical complexity to an absolute minimum. This minimalist approach also increases the reliability of the positioner as well as the implemented diagnostic features.

HMI (human machine interface) provides access even to complex diagnostic data in the positioner or using communication.

External sensors in special cases for example for leakage detection or pressure monitoring of a control chamber to detect packing leakage.

Auto-tune: Zero and span calibration, control parameter optimization and monitoring of correct positioner attachment are performed automatically without any user interaction. Auto-tune must be implemented in the positioner itself without relying on external resources.

Scope of valve diagnostics

Diagnostics target the behavior and the condition of the positioner and the mounted valve. Additionally, conclusions can be made on the entire process, provided they affect the valve's control performance. **Table 1** lists faults that can be detected.

Diagnostic objectives include:

- Increased availability due to early detection of valve wear or damage
- Changeover from scheduled maintenance intervals to maintenance on demand
- Improved process yield due to improved control accuracy and stability

On/off valve diagnostics

On/off valves are operated in either open or closed position. Accordingly, they are usually fitted with a solenoid valve to operate them and with limit switches to indicate the valve position. Besides requiring the best possible availability, reliable operation is of primary concern regarding these valves. The valve diagnostics have to answer the question on whether the valve will move on demand despite not having been moved for years. This makes the use of positioners with diagnostic functions safety-relevant. By applying the methods of IEC 61508/IEC 61511, the achieved degree of safety can be quantified by determining the reliability data (**Figure 1**).

The following diagnostic methods are particularly important for on/off valves:

Partial stroke test

This test can be performed while the process is running. The on/off valve is stroked, for example 10 % from its open position in the closing direction.

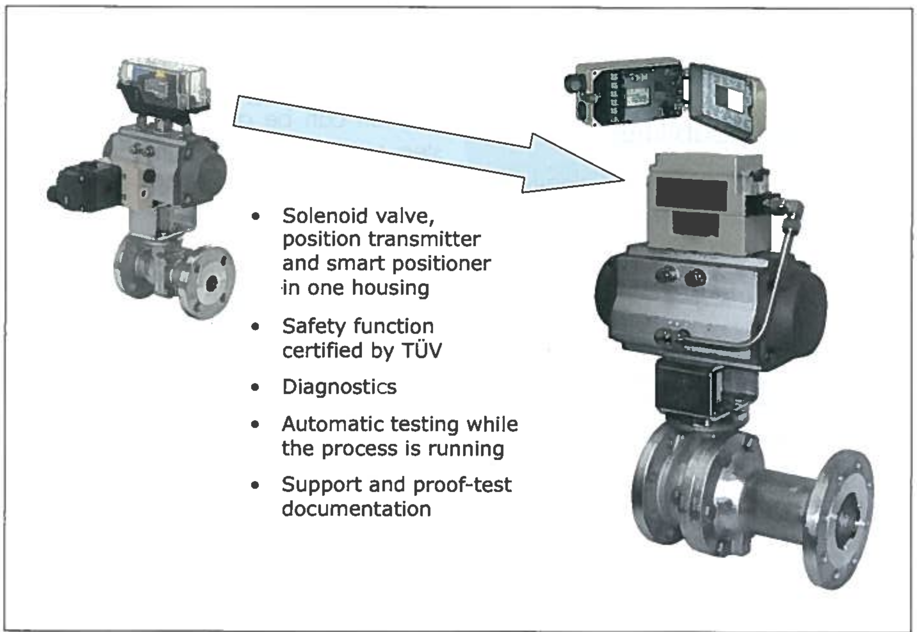

Fig. 1: Example for automation of an on/off valve

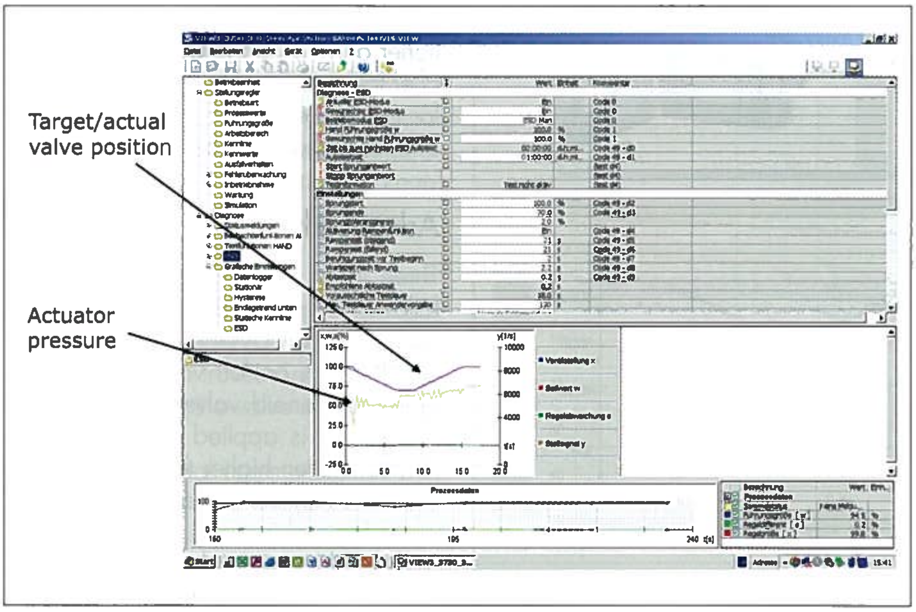

Fig. 2: Partial stroke test logged by the positioner

Table 2: Information gained from partial stroke test

Inductive limit switch	Partial stroke test, step response	Partial stroke test, ramp function	Diagnostic alarm
X	X	X	Valve in closed position
	X	X	Exact valve position and set point deviation
	X	X	Valve transit time
	X	X	Dead time
		X	Uniform valve stroking
	X	X	Overshooting
		X	Actuator pressure (breakaway torque, friction)
	X	X	Operating hours counter (NAMUR Recommendation NE 107)
	X	X	Permissible temperature exceeded (NAMUR Recommendation NE 107)

As a rule, this does not affect the process, yet provides evidence that the valve can still be moved. The stroking procedure can be specified in detail by entering the corresponding parameters (start point, end point, initialization and maintenance times, type of stroking – ramp or step response). To prevent overshooting or other unwanted operating states, cancelation conditions, such as test duration, overshoot and minimum actuator pressure, can be defined for the test. The partial stroke test supplies in-depth data: travel histogram, actuator pressure trend, dead time, t63, t93, overshoot etc. (**Figure 2** and **Table 2**).

The analysis of these parameters provides a higher-level test status: "Test OK" or "Test not OK". Alarms can be assigned to these test states, which are indicated either using digital communication or a switching binary output. **Figures 3** and **4** impressively demonstrate how changed friction is shown in a travel histogram. By way of example, both test methods – step response and ramp function – are performed. In both cases, the effect friction has, for example on the dead time and control performance, is easily recognizable and, as a result, can be diagnosed. Due to the high dynamics of the step response test, a high initial force is required. The actuator must be completely vented, which is easy to recognize in Figure 3. The ramp function (Figure 4) works closer to a balance of forces. In this test, the amount of air that the actuator vents is an excellent indicator of how much force the actuator has to apply. By monitoring a threshold value for the actuator pressure, an alarm can be generated if the friction changes to warn that maintenance may be needed.

Full stroke test

Safety instrumented systems must be tested at regular intervals to prove their full functioning. The proof test interval is currently one year in most plants used in the process industry, while much longer test intervals are common in the petrochemical industry. Normally, this test involves the valve being closed under supervision and then the test result being

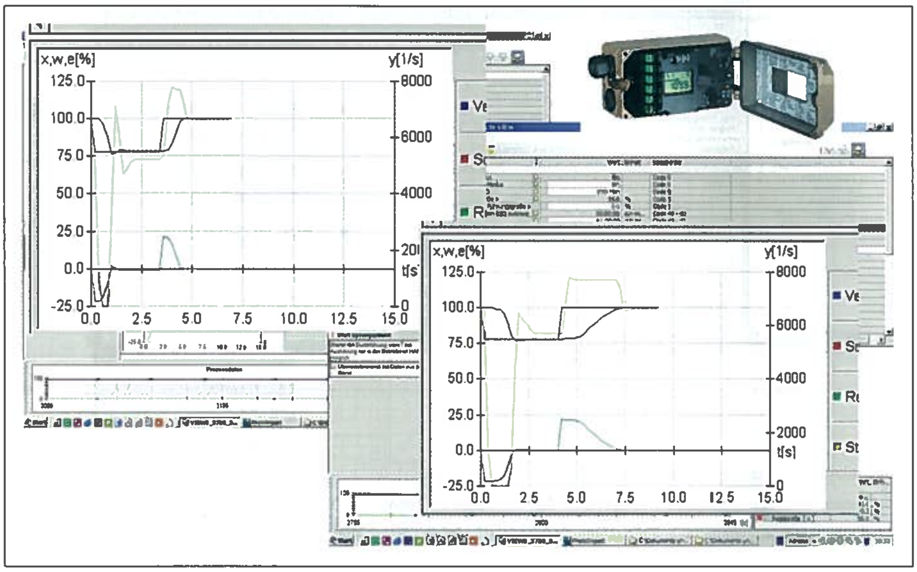

Fig. 3: Step response – increased friction detected

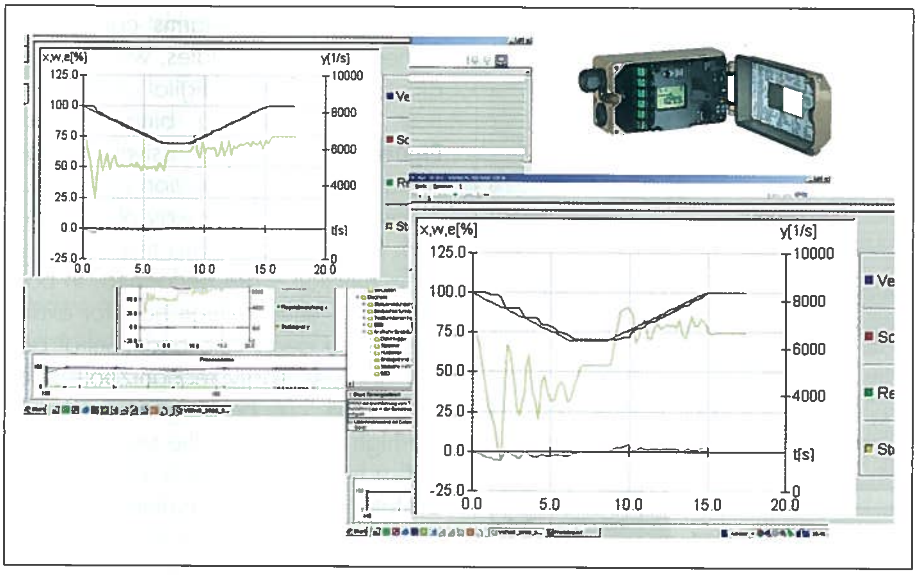

Fig. 4: Ramp function – increased friction detected

documented. This test method can be automated using a positioner. The data gained by the positioner are substantial (precise measurement or detection of dead time, closing time, end position, uniform valve stroking over the entire travel range etc.). In addition, the automated, time-stamped records of the test results saved in a database provide a considerable gain in test reliability and diagnostic validity. By comparing the test data with previous test data, trend statements can be made about the valve's condition.

Monitoring spurious trips

The previously described data logger and data log triggering allow the functioning of the on/off valve to be documented in the event of an unscheduled plant shutdown (spurious trip) as well. The positioner records the spurious trip on site at the valve. The data are saved in the non-volatile memory of the positioner and can be read out at any time after the event as documented evidence for the flawless functioning of the valve and for further analysis (**Figure 5**).

Advanced ideas

Three ideas are briefly outlined in the following:

- When an on/off valve is activated by a solenoid valve, the full supply pressure is applied to the actuator. This is often higher than the pressure needed by the actuator to overcome the force of its return springs. This additional pressure leads to a dead time during closing, which can amount to several seconds and reach a critical level in some plants. In contrast, a positioner would be capable of controlling the position of the on/off valve in the open position. The pneumatic actuator would be supplied with exactly the pressure required to reach the open position. The total closing time would be shortened considerably this way. Furthermore, diagnostics, such as small changes in travel around the set point to detect friction, could be performed as part of this position control function.
- Modern, conventional partial stroke tests are performed with a ramp movement that does not disrupt the flow of the medium through the valve. Ramps of approx. 10 % are typically used, which do not restrict the effective cross-section of the flowing medium to correspond with the characteristic, for example, of ball valves. **Figure 6** shows such a measurement. Closing the valve further, to a position of approx. 80 % for example, affects the medium flow (**Figure 7**). This test method would considerably enhance the diagnostic coverage, allowing the functioning and integrity of the throttling element to be assessed.
- By using a positioner on a safety valve, the solenoid valve would be no longer be needed at all as the venting of the actuator in case of emergency shutdown would be taken over by the positioner. Positioners

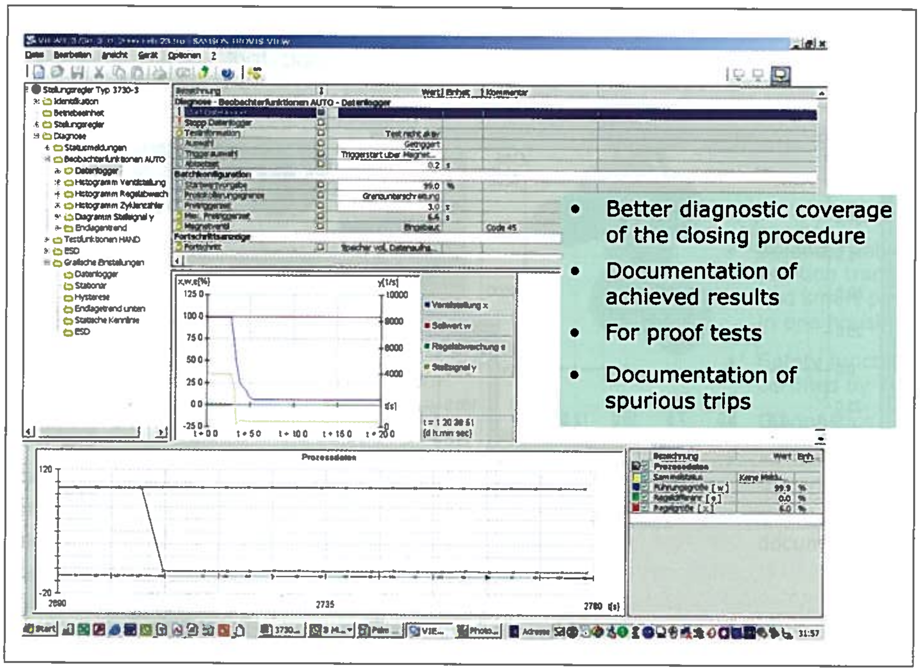

Fig. 5: Spurious trip recorded

with the corresponding certification are already available.

Figure 8 shows an optimal configuration according to today's knowledge of field units and their connection to a control system. It meets all requirements:

- Partial stroke test
- Full stroke test
- Monitoring and logging of spurious trips, documentation of valve stroking over the entire travel range
- Controlling of the valve in open position
- Optional digital communication with a higher-level asset management system.

It is beyond the scope of this short article to compare this configuration to others that are in use today.

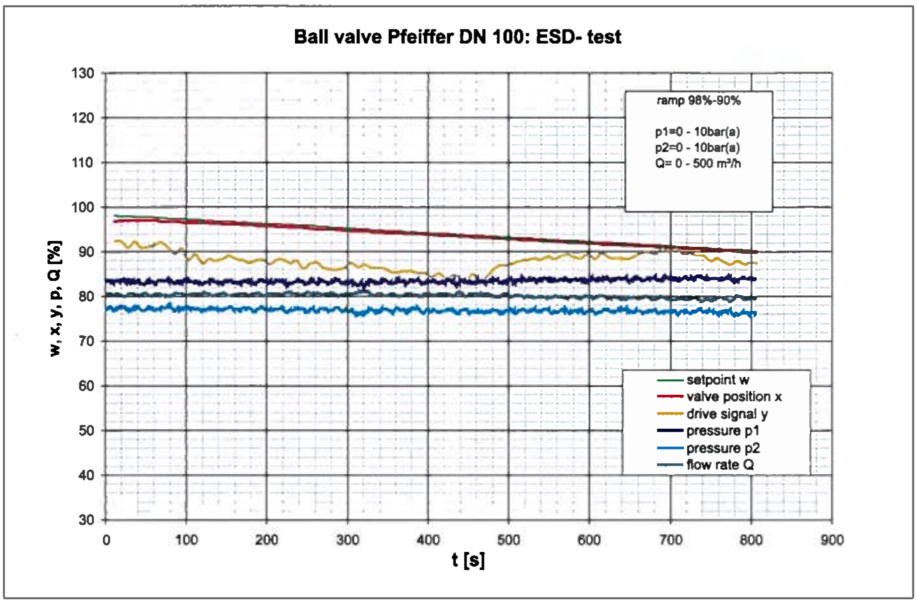

Fig. 6: Partial stroke test: flow rate unaffected

Diagnostics using smart positioners in association with IEC 61511

Plant operators in the process industry must meet the following requirements regarding safety instrumented systems:

- Systematic failures must be eliminated,
- Statistical failures must be calculated which must be below the specified limits,
- Architectural constraints: The general guideline is that SIL 2 instrumentation can be equipped with single channels, while redundancy is generally required for SIL 3 (this statement is actually a shortened summary of the sophisticated statement of the standard).

Systematic failures

The crucial point behind the ideas and demands presented in the standard is the implementation of the safety life cycle [7]. To avoid systematic failures, an exact understanding of the process and the resulting valve sizing are critical [2, 3]. The requirements of the safety life cycle regarding safety valves can be supported by a smart positioner with diagnostic capabilities as follows:

- Mounting and start-up (monitoring to ensure correct attachment of the positioner, correct assignment of the BPCS outputs, proper functioning, performance data, such as transit time, exact end position etc., documentation of achieved results)
- Maintenance (proof tests automatically performed, performance data of the safety circuit, documentation of achieved results)
- Documentation of spurious trips (monitoring and time-stamped logging of spurious trips, provision of data to analyze the behavior of the safety circuit)
- Documentation of safety circuit behavior, support in compiling data for proven-in-use rating

Statistical failures

Partial stroke testing while the process is running has already been outlined. The objective of partial stroke tests is to extend the plant running time, i.e. longer intervals between proof tests. The maxi-

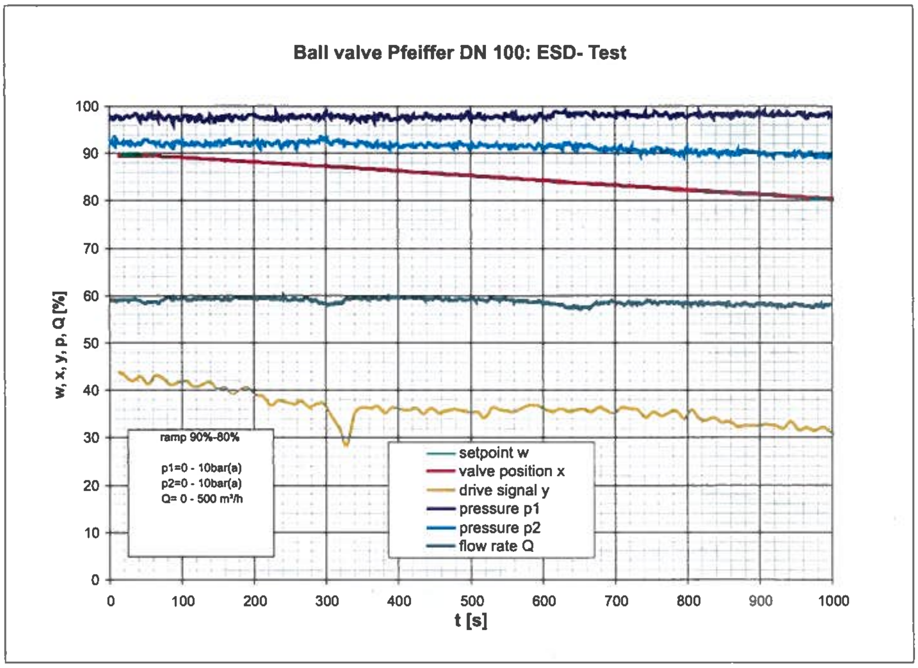

Fig. 7: Flow rate slightly reduced

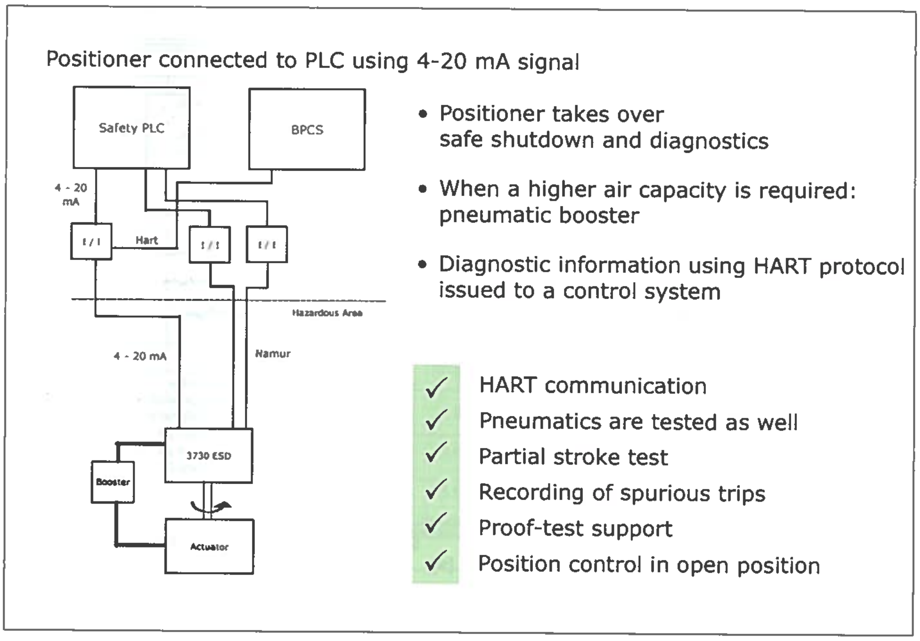

Fig. 8: Possible integration into a control system

mum interval between tests can be determined quantitatively by the PFD and assignment to the desired SIL (safety integrity level):

$PFD_{(1oo1)} = DC \times \lambda_d \times TI_a/2 + (1\text{-}DC) \times \lambda_d \times (TI_m/2)$

λ_d = Dangerous failure rate
TI_a = Partial stroke testing interval
TI_m = Interval between proof tests
DC = Diagnostic coverage factor [4]

The diagnostic coverage factor is particularly important in this case as it specifies the percentage of failure modes that can be detected by the online diagnostics in relation to the dangerous failure rate. This definition results in the following requirements:

- All failure modes must be analyzed and known
- The applicability of the diagnostic methods must be known

The process conditions in the chemical industry are manifold and vary considerably. As a result, the requirements placed on a safety valve cannot be generalized but need to be examined for each case of application [5]. This proves that the user's request to the manufacturer to specify the exact diagnostic coverage factor is not eligible. The manufacturer can and must make statements concerning:

- The available diagnostic methods
- Reliability data for valve and positioner together with their sources
- Instructions for the intended use of valve and positioner

A realistic diagnostic coverage factor may be between 50 % and 80 % depending on the process. Nevertheless, the factor may also differ in some cases. This results in a possible extension between proof tests by a factor of approximately two (**Figure 9**) [6]. Assumptions that much higher values, for example a factor of five, are achievable, are to be examined scrupulously to ensure validation of all assumptions and also be correlated with operating experiences.

Architectural constraints

In compliance with IEC 61511, it is not possible to reduce the requirements on the HFT (hardware fault tolerance) by performing partial stroke tests.

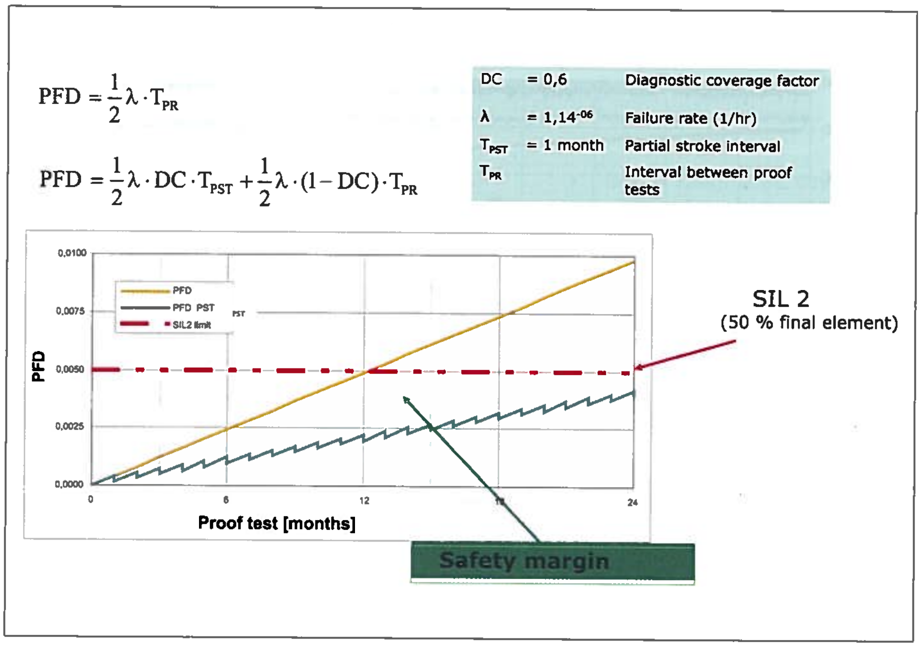

Fig. 9: Effects of partial stroke test

Conclusion

- Valve diagnostics performed by positioners are a fully developed technology, which can be used beneficially on control valves as well as on/off valves.
- Replacing the solenoid valve on on/off valves by a modern positioner with diagnostic functions enhances the reliability and can extend the interval between proof tests.
- IEC 61511 provides guidance for a quantitative assessment of the reliability of safety instrumented systems and the effect caused by using different instrumentation versions. This assessment can be included in the estimation and evaluation of investments and life cycle cost.

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The Company

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