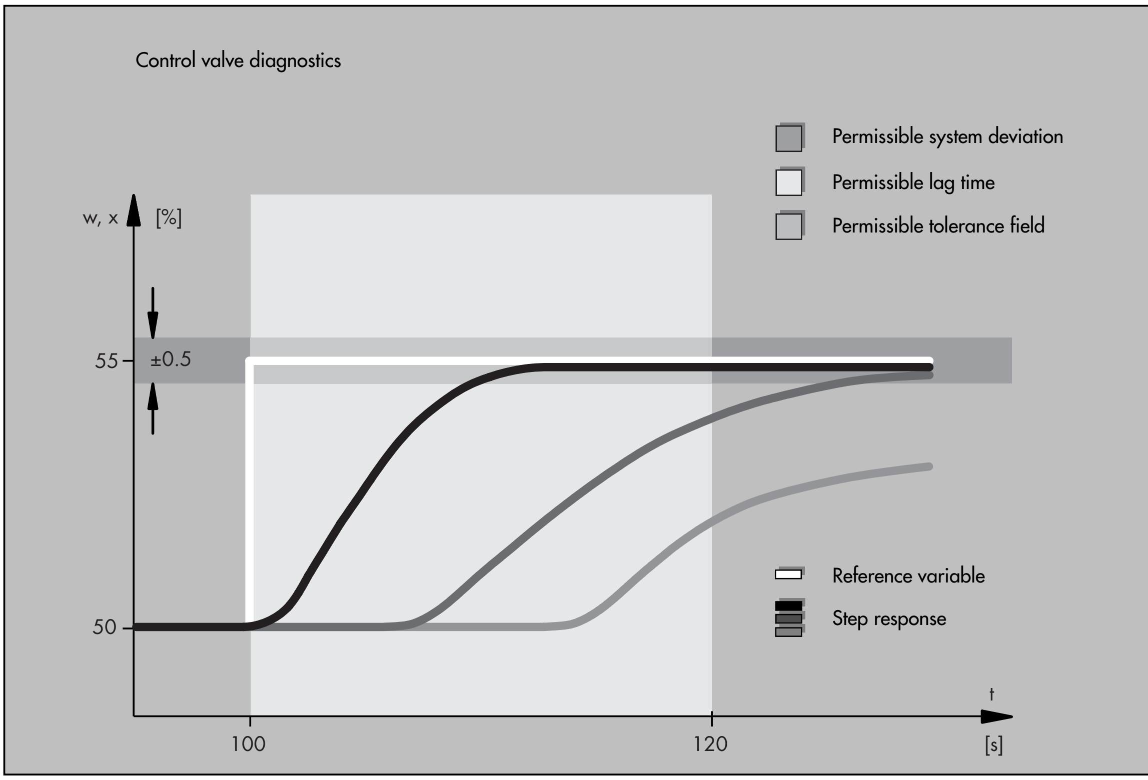
Improved Process Plant Reliability and Maintenance with Digital Positioners



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by:
Dr.-Ing. Jörg Kiesbauer
Dr.-Ing. Heinfried Hoffmann

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Jörg Kiesbauer and Heinfried Hoffmann, Frankfurt am Main

Dr.-Ing. Jörg Kiesbauer is head of development test department for SAMSON AG (Germany, Frankfurt/Main). Work fields: R&D in the field of control valves including accessories and self-operated regulators (flow capacity, sound emission, failure diagnostics, optimization of prediction methods, etc.).

Dr.-Ing. Heinfried Hoffmann is corporate Vice President SAMSON AG (Germany, Frankfurt/Main) and responsible for the R&D department.

In der Prozeßautomatisierung kommen heutzutage zunehmend kommunikationsfähige Sensoren und Aktoren mit digitaler Signalverarbeitung zum Einsatz.

Hierdurch erhalten speziell Stellgeräte mit digitalem Stellungsregler wichtige Zusatzfunktionen mit zahlreichen Vorteilen für den Anwender durch eine verbesserte Regelung und durch die Möglichkeiten vorbeugender und zustandsorientierter Wartung mit Fehlerdiagnostik sowie der Datenarchivierung. Dies trägt zur produktionsintegrierten Instandhaltung und zur verbesserten Prozeßzuverlässigkeit bei.

Allerdings unterscheiden sich die auf dem Markt heute verfügbaren digitalen Stellungsregler in der Gerätetechnik und in der Bedienungs- und Diagnosesoftware teilweise doch erheblich. Die Folge ist oft Unklarheit bei den Anwendern hinsichtlich der Möglichkeiten und Vorteile digitaler Stellungsregler. Dieser Aufsatz soll hierzu einen umfassenden Überblick geben.

Improved process plant reliability and maintenance with digital positioners.

In the modern process automation industry more and more digital sensors and control devices with the ability to communicate with the process control system are installed.

Especially control valves with digital positioners have additional important functions with many advantages for the user in the form of improved control loop quality and the possibilities of supervision and failure diagnostics including data storage. This leads to a process integrated maintenance and more process plant reliability.

But there is a difference between the digital positioners being available on the process automation market concerning the device constructions and the operator interface and failure diagnostics software. The result often is missing clearness about the real possibilities and advantages of digital positioners. This paper gives a detailed overwiew of actual developments in the field of digital positioners.

1. Chances of digital positioners

The upward pressure on costs as well as strict environmental safety requirements make great demands on the maintenance departments of process plants. On the occasion of the 1995 NAMUR main conference [9] a maintenance and repair study was presented, covering approx. 1500 control valves (Fig. 1) removed for inspection. It showed the significance of well-aimed maintenance strategies in connection with safe, but cost-efficient process procedures. According to the study, removal from the system, i.e. piping, could have been prevented for 80 % of all control valves.

Whether theses figures can be generally applied is doubtful, however, they help explain the necessity for up-to-date "smart" or "intelligent" control valves with communicative abilities and automatic supervisory or diagnostic functions provided by digital positioners. This is also the reason why in recent years control valve development activities have mainly been focused on electropneumatic positioners as the "intelligent" interface be-

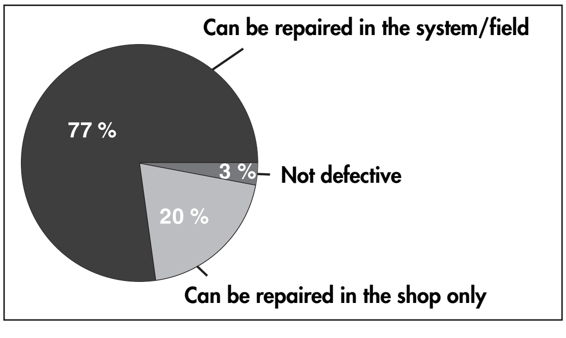


Fig. 1:
Maintenance and repair study (NAMUR main conference 1995) [9]

tween process control station and the control valve as the actuator in the field.

In addition, the study showed that approx. 64 % of all inspected control valves malfunctioned, because the positioner had not been properly adjusted. These types of faults could be considerably reduced by using actuators with integrally mounted positioners, because unintentional mechanical deformation and displacement would be prevented [8].

2. Main positioner tasks

Fig. 2 illustrates a typical process automation application from the valve manufacturer's point of view. The process control loop for controlling process variables (e.g. input pressure p_1, flow rate Q, temperature T) receives several sensor input signals and generates an input signal for the control valve (reference variable w). The input signal depends on the configuration of the process control loop and corresponds to a certain valve position (controlled variable x). The positioner processes the input signal w in the cascade control loop such that valve position $x = w$ is reached. This fast cascade control loop has proven well for existing disturbance factors (packing friction, valve flow, etc.).

Most process engineering applications require single-acting pneumatic actuators with diaphragm and springs.

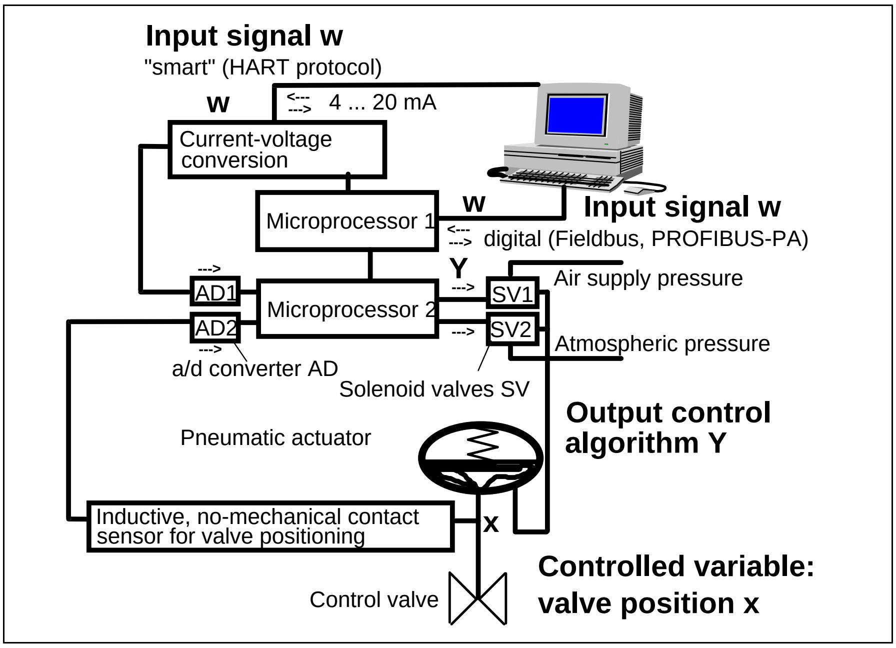


Fig. 3: Digital positioner design (SAMSON Types 3780/3781/3785)

The positioner uses the air supply pressure to fill or vent the actuator diaphragm chamber, depending on the system deviation $x_d = w - x$.

3. Analog and digital positioners

Conventional analog positioners attached to control valves with electro-pneumatic actuator form high-precision electromechanical components. Their input signal range is set to 4(0) ... 20 mA in standard applications. This signal carries *both* types of information, "no signal (0 mA)" and "current size (4(0) ... 20 mA)". An i/p converter is used to convert the electric input signal to a pneumatic signal. The valve position x is transferred to a measuring spring via lever mechanism.

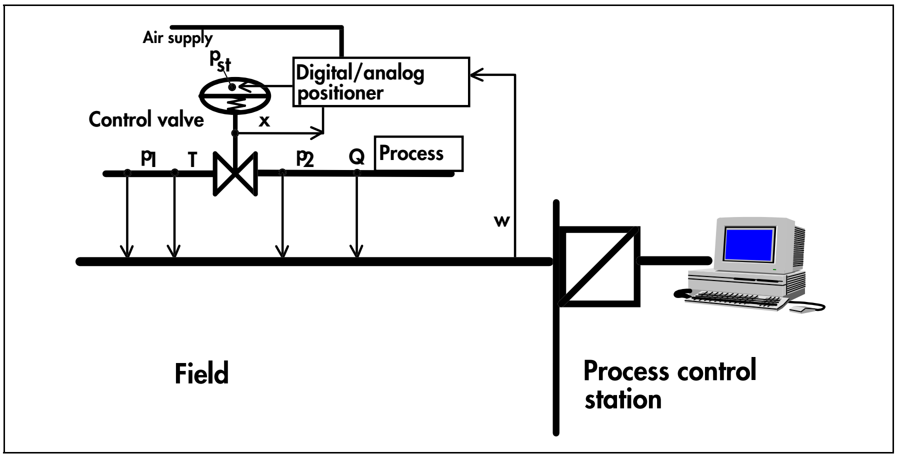
A flapper/nozzle assembly with a pneumatic amplifier is used to establish an equilibrium in this force-balanced mechanical system, in order to reach the proper valve position according to the set point [7].

The adjustment of zero and span directly at the control valve is an iterative and time-consuming process.

Control response and functionality, e.g. handling, archiving, fault diagnostics, alarm functions, can only be improved with the help of digitally processed signals. For clarity, the principal structure of a digital positioner is shown in Fig. 3. The main components comprise

- microprocessor
  - for storing data/processing input and output signals
  - for the control algorithm to generate an internal control signal Y (input pneumatic supply unit)
  - for configuration and initialization
  - for communication
- sensor in the following two designs for valve positioning

Fig. 2: Typical process automation application



– inductive (no-contact and no-wear)
– or potentiometer (mostly conductive plastics potentiometer)

- pneumatic supply unit in the following two designs for the filling and venting of the actuator diaphragm chamber:
  – pilot valves, such as piezo valves or solenoid valves, with pneumatic amplifiers
  – i/p converters as standard version or with frequency modulation
- A/D converters for valve positioning and input signal (only for HART protocol).

The positioner derives auxiliary power from live zero, i.e. from a minimum 4 mA input signal which is made possible through the application of low-power microelectronic components. If the electrical auxiliary power is too low, a "Communication fault" error message is generated. The so-called HART protocol can be seen as a predecessor of purely digital communication. HART communication utilizes the conventional analog current signals of 4 ... 20 mA which are superimposed by higher-frequency, serially transmitted sine signals representing the digits 0 and 1. This technology allows easy conversion of existing systems with conventional wiring. Hand-held terminals or computer software, such as IBIS Operator Interface (*Hartmann & Braun*), Cornerstone (ASTEC), CommuWin (*Endress + Hauser*), SIPROM PS (*Siemens*), etc., enable digital communication [2; 7; 8].

Fieldbus systems (Fig. 2) use digital signals for communication only, which reduces their susceptibility to faults. Compared to the HART protocol, fieldbus system technology provides more economical and higher data transmission rates between process field devices and process control stations as well as between sensors and actuators in the field [3; 4; 5; 6]. However, the question, which fieldbus standard, PROFIBUS-PA [5], FOUNDATION Fieldbus, etc., will become generally accepted in future, or whether several standards will exist side by side, has not been resolved yet.

The most significant advantage of digital positioners using digital communication as opposed to conventional analog positioners, is their capability of bidirectional data exchange between the control room and the field. Data can be stored, updated and processed by the microprocessor. These characteristics provide a certain type of remotely applicable "intelligence" to a control valve that is equipped with a digital positioner.

Additionally, software limit switches, fast initiation of, e.g. fail-safe action through software controlled and thus fully opened solenoid valves in the positioner, as well as position feedback are standard features of digital positioners. These digital positioners are already today available for the same price as analog positioners which are only optionally equipped with these additional functions.

4. Automatic start-up and configuration options

One of the most significant advantages of digital positioners is a fully automated, non-iterative start-up. During this initialization procedure, zero, span and gain are automatically adjusted.

The disadvantage of some digital positioners available on the market is, however, that basic minimum configuration data must be first entered via hand-held terminal or computer.

A better solution are control valves with integrally mounted digital positioners that can be directly adjusted on site without hand terminal or computer via a manual button to move the control valve to closed position. The displacement sensor is set to zero via hand-operated lever (Fig. 4). The rated travel of the control valve is recognized via the pick-up lever coding so that mechanical stop is not required for rated travel. Initialization is started via operating button. After initialization, the control valve is standard configured and ready for operation. The fail-safe action is automatically determined.

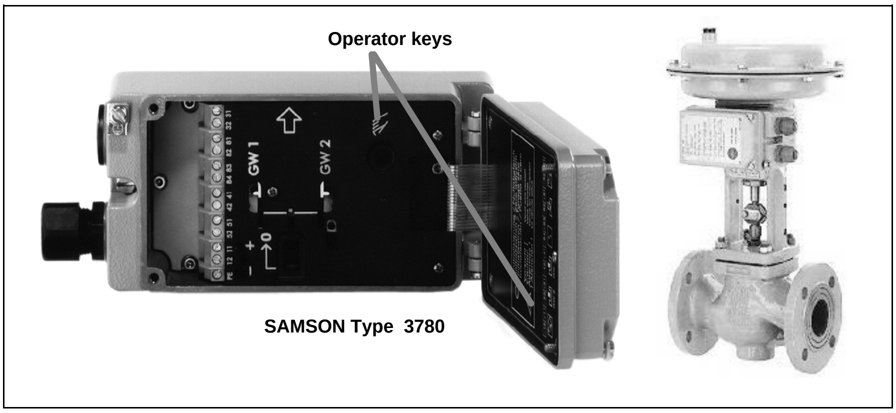
Another advantage is the clear definition of zero including the configurable tight-closing function

- fail-safe position "Spring closing": diaphragm chamber fully vented
- fail-safe position "Spring opening": diaphragm chamber filled (supply air pressure).

An individual configuration or parameterization can be performed via hand-held terminal, PC (HART protocol, fieldbus) or entered directly in the field for later identification and optimum adaptation to the task. The following settings can be adjusted.

- *Loop/tag identification*:
  Positioner type,
  Loop/tag number,
  Positioner serial number,

Fig. 4: On-site calibration via manual keys (zero and displacement sensor)



Valve serial number,
Actuator serial number,
Description of application,
Description of calibration site,
Date,
Program version,
Message, e.g. for maintenance.

- *Valve travel control:*
  k_v-x-characteristic (lin., eq. perc. open/closed, eq. perc. reverse, freely definable co-ordinates) → for linear characteristic,
  Minimum lower travel limit,
  Maximum upper travel limit,
  Lower travel limit for safe closing function,
  Upper travel limit for maximum opening function.
- *Input signal control:*
  Operating direction ($I = 4$ mA: valve open/closed),
  Set point input (manual, automatic, fail-safe position, digital).
- *Actuator type:*
  Linear/rotary,
  Integrated/NAMUR attachment,
  Single-/double-acting.

5. Optimization and supervision of the positioner control loop

With analog positioners, the Xp restriction must be adjusted manually. Digital positioners, however, provide operators with the advantage of direct input of digital control parameters for the main task of "positioning the valve".

The control quality and the control loop's dynamic response are influenced by the following factors (Figs. 5 and 6, [1; 7]):

- Proportional-action coefficient K_P,
- Derivative-action coefficient K_D (*D* component)
- Integral-action coefficient K_I if applicable (*I* component)
- Dead band $x_{dead\ band}$,
- Tolerated overshoot,
- Entered opening and closing time with a lower limit that is measured by/depending on the system.

With digital positioners, the control loop algorithm in the microprocessor repeatedly recalculates the internal control signal *Y* (Fig. 3) in small time intervals depending on the control loop parameters and the system deviation x_d [1], e.g. for the PD controller:

$$x'_d = x_d + K_D \cdot \frac{d\,(x - w)}{dt},$$

$$(x_d = w - x);$$

$$Y = f(x'_d, K_p).$$

For some digital positioners, such as FIELDVUE by *Fisher Controls*, depending on the size and the type of actuator, so-called tuning sets are used for the proportional-action and the derivative-action coefficients. These coefficients are used together with the air supply pressure to determine the quality and the dynamic response of the control loop. A true self-adaptation does not take place, but the user can evaluate the dynamic controller response based on step responses or self-configured time functions for the input signal and then modify the parameters.

Other manufacturers, e.g. *Neles-Jamesbury*, are using a mathematical, non-linear model which analyzes the real valve behavior on-line and determines the proper internal control signals. With this method, it is expected to achieve a faster response and more accurate positioning of the valve stem in digital positioners than in analog positioners. It must be considered that this mathematical model requires the input of valve specific data that may not be completely available for third-party products.

In general, digital positioners should be capable of automatically optimizing the control loop parameters for any actuator/control valve system. The characteristic $Y = f(x'_d, x_{dead\ band}, K_{p\_y})$ (Fig. 5, top) is especially suited to pilot valves, such as piezo or solenoid valves that are normally controlled by pulse-width modulated signals (Fig. 5, bottom) [1]. In the area of the dead band $x_{dead\ band}$, e.g. 0.2 % referred to the rated travel, the pilot valves are not active and the air consumption is nearly zero. The configurable, thus, enterable dead band determines the positioning accuracy which is only difficult to realize in practice with digital positioners that are equipped with conventional *i/p* converters and PD control action. Although a higher proportional-action coefficient reduces the system deviation, the control loop could easily become instable.

During the automatic start-up, zero is adjusted first and then the positioner is initialized and ready for operation. During this off-line initialization routine, the parameter Y_{min} (Fig. 5) can be optimized for several ranges of the manipulated variable as well as for filling and venting by using a certain minimum valve travel time as an evaluation criterion independent of the valve/actuator combination. The result is an always similar dynamic behavior

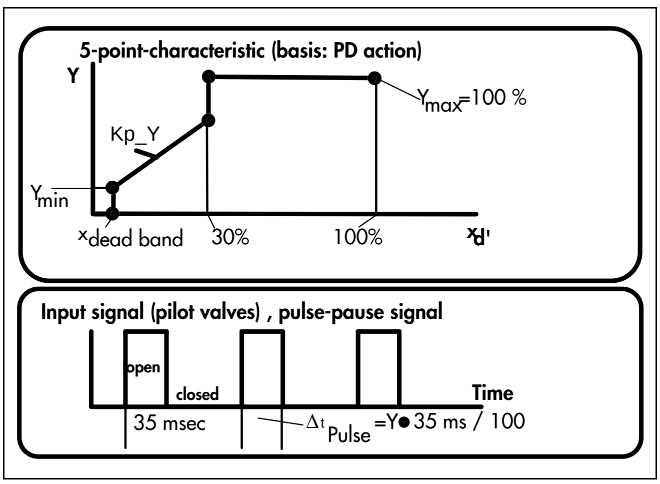


Fig. 5: Internal control signal with digital positioners (SAMSON Types 3780, 3781 and 3785, with solenoid valves)

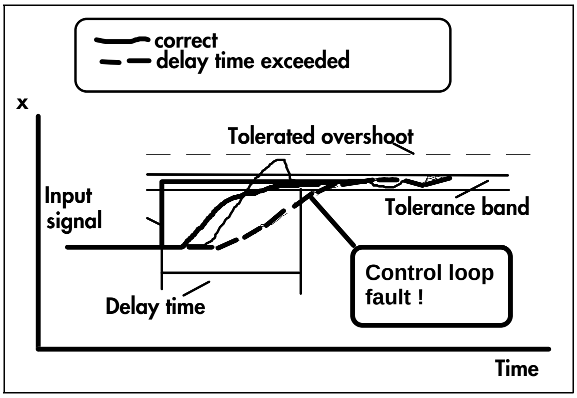


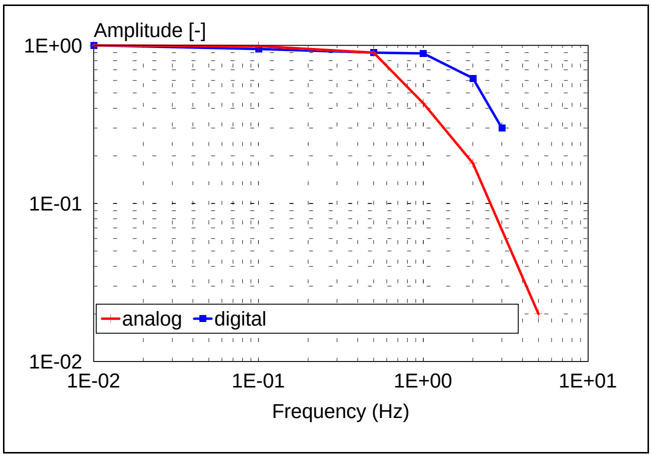
Fig. 6: Supervising the control loop of digital positioners

in a small signal range with otherwise identical control loop parameters.

A self-adaptation of this minimum control signal is also possible on-line. In addition, the overshoot is controlled and reduced to a minimum (Fig. 6). Furthermore, digital positioners provide on-line monitoring functions (Fig. 6). An alarm message is issued if

- the tolerance band entered by the operator is exceeded by the valid set point.
- the tolerance band is not reached within the so-called delay time t_N after the step in the reference variable.
- the zero tolerance limit is exceeded or not reached.

In control engineering, it is standard procedure to analyze the dynamic control loop behavior with the help of the Bode diagram and the step-response method, even for non-linear characteristics with small signal changes around the operating point (linearization). Comparative tests of analog and digital positioners (Fig. 7) show that digital positioners have an equally well dynamical behavior as the best analog positioners.



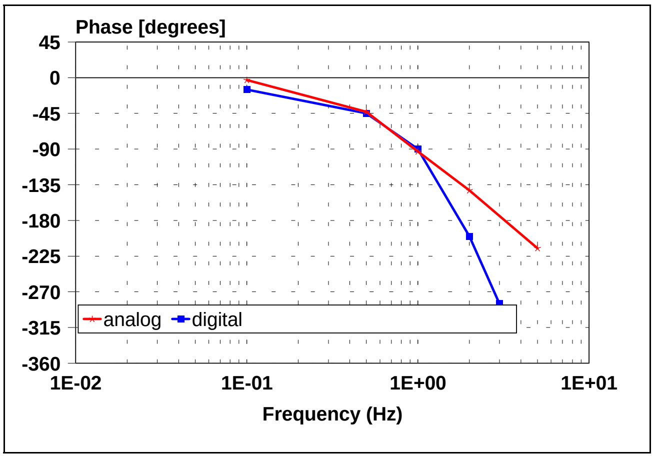


Fig. 7: Comparison of the dynamic behavior between analog and digital positioners

6. Monitoring and diagnosing control valve performance

As mentioned above, the possibilities provided by digital positioners, such as

- "remote control" including communicability,
- automatic start-up with additional configuration options,
- optimizing and monitoring the valve position,

are a significant contribution to process control improvement, because they allow functional problems as the result of an incorrect positioner calibration to be signalized and minimized considerably.

In addition, digital positioners are capable of monitoring and diagnosing the entire control valve performance. Basically, the following three areas regarding control valve performance are supervised.

- Initialization during automatic start-up off-line
- Status request options off-line and on-line
- Detailed fault diagnosis off-line and on-line

Depending on the applicable fault detection and diagnosis methods, it must be further differentiated between off-line and on-line process plant status.

6.1 Automatic start-up off-line

Already during automatic start-up, the following faults can be detected in the initialization phase and must be absolutely prevented [7]:

- The valve position does not change at all or in one direction only.
- The zero point is outside the tolerance range.

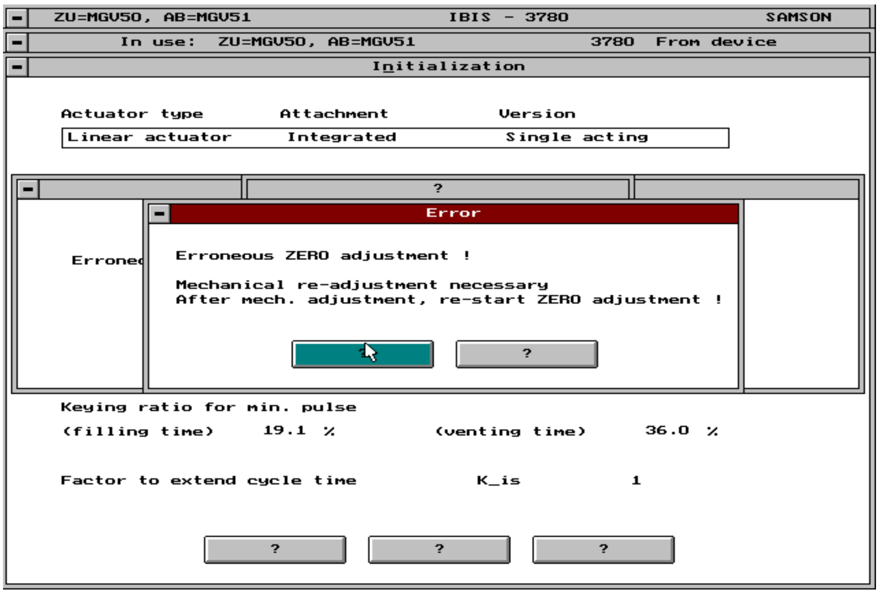


Fig. 8: Warning and instructions in case zero is not properly adjusted for the control valve

- The maximum travel is smaller than the configured rated travel.
- The valve position cannot be corrected according to the reference variable.
- The minimum control signal Y_{min} is erroneous or too small (limited proportional band).
- The valve position changes, although the pilot valves are deactivated (actuator leakage).
- The rated travel range cannot be fully passed.

Such faults are indicated via handheld terminal or software and displayed with clear instructions and recommendations on how to eliminate them (Fig. 8).

- Air supply pressure too low/not stable.
- Improper mechanical attachment.
- Lever not properly hung.
- Actuator leakage.
- Check control parameters ($x_{dead\,band}$, K_P, K_D).
- Defective device.
- Actuator volume very small, installation of signal pressure throttle recommended.
- Zero point shifting (contamination/wear).

6.2 Status request options off-line and on-line

Digital positioners feature a series of status request options which are selectable to be issued in cycles with logging and alarm signaling functions, e.g. via HART protocol, fieldbus or analog via fault alarm switch.

- *Instrument information on the loop/tag:*
  Positioner type,
  Loop/tag number,
  Positioner serial number,
  Valve serial number,
  Actuator serial number,
  Description of application,
  Description of calibration site,
  Date,
  Program version,
  Message, e.g. for maintenance.
- *Positioner (fault in electrical hardware):*
  Communication fault,
  Insufficient power supply, e.g. HART protocol < 3.6 mA,
  Memory blocks for control and communication data cannot be written or checksum error,
  Measuring mode, e.g. input and output signals are not within the measuring range or A/D converters do not function properly,
  Sensor fault, e.g. of valve position sensor,
  Program fault.
- *Current activities or status:*
  Calibration process,
  Diagnosis process,
  Configuration modified,
  Standard control operation.
- *Monitor function "Current instrument signals":*
  Input signal w,
  Internal control signal Y,
  Valve position x,
  System deviation x_d,
  Some positioners may also indicate pressure p_{st} in the diaphragm chamber,
  Some positioners may also indicate the temperature in the positioner.
- *Monitor function "Monitoring limit values":*
  System deviation, lag time,
  Zero point,
  Travel counter,
  Change-of-direction counter,
  Binary input, e.g. pressure switch for untight stuffing box or bellows seal.

Comments:

Status requests regarding the electrical hardware allow direct faults to be detected in the positioner itself. Information about the current positioner activities are also important.

The monitor function "Current instrument signals" indicates the currently valid process conditions for the control valve as reference variable w and functional accuracy of the positioner (control loop deviation).

Instructions for maintenance and possibly critical conditions can be derived from monitoring the limit values [8].

In the event that errors occur during control valve positioning, a new initialization (see section 6.1) can bring clarification, unless a status request on the electrical hardware has already identified possibly existing device defects.

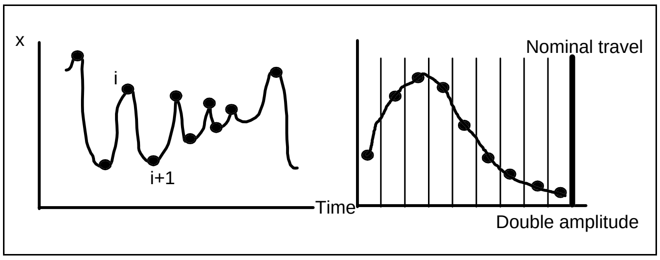


Fig. 9: Distribution function for evaluation of stresses caused by load changes (correct cycle counter)

Zero shifts below the lower range value of zero may indicate plug or seat wear, while the cause for zero shifts above the lower range value could be a possible contamination, e.g. through welding particles.

The logging and integration of valve-position changes over the entire operating time allows the valve stem travel to be counted like kilometers in automobiles. To ensure the proper observance of maintenance intervals, it is useful to enter limit values based on the service life of components, such as packings or metal bellows seals [8]. Control valve manufacturers could contribute to this significantly with their experience gained from continuous tests on the test bench under standardized test conditions, e.g. medium, operating conditions with nominal pressure, travel amplitude. The number of endurable nominal travel cycles, however, could turn out to be lower or higher under actual process conditions due to other media, operating conditions, travel amplitudes, real collective cycles of nominal travel, etc. In any case, it is absolutely necessary to access the respective user's experience with his particular plant. The disadvantage of a pure travel counter without counting the changes of direction as well, is that for a safe prediction only the number of half rated travel amplitudes can be concluded from the registered travel. In practice, however, only one or a few operating points are used for control in most cases, so that the travel amplitudes are generally smaller than half the rated travel. This would result in longer maintenance intervals with lower maintenance costs.

Additional counters to register the changes of direction could be a remedy for these uncertainties. The digital positioners that are available on the market with this option are not up to the task, because only the actual changes of direction are counted without registering the size of the travel amplitude.

As usual with endurance strength calculations, the load collective must be evaluated on the basis of a class distribution function (Fig. 9) for the dominant cycles of nominal travel in the form of direction changes ($x_{i+1} - x_i$) that are graded in valve position range classes, e.g. 10, 20 ... 100 %. The dominant travel amplitude can be assigned with a tolerable number of nominal travel cycles.

Today, this concept is failing because real-time supervison requires high memory capacities in digital positioner controllers. These capacities will become available for future positioner generations only due to more powerful microelectronics at the same low energy supply level (e.g. 3.6 mA with the HART protocol). At present, therefore, the safest method is to determine the total travel with conversion to full travel in connection with a tolerable number of nominal travel cycles based on the full travel motion.

The binary input enables the detection of special critical conditions, e.g. reaction of the pressure switch to stuffing box leakage, see also section 6.4).

6.3 Detailed fault diagnosis off-line and on-line

Detailed fault diagnosis options help operators detect errors or critical conditions in time before they result in a perceivably defective performance of the control valve or sometimes of the entire process plant. In this respect, it is important that clear instructions for maintenance and repair as well as for the process control station be issued in due time. According to the manufacturers of systems that have long been available on the market for process automation, e.g. VALTEK STARPACK by *Valtec International* or FLOWSCANNER by *Fisher Controls*, their positioners - analog or digital - provide these options by using additionally installed sensors on the control valve for input and output pressure, signal pressure, temperature, flow rate and valve position. These sensor signals are picked up by a connection board on the valve. Special analyzing systems in the form of "portable telecommunications test sets with integrated PC or notebook and software" evaluate the measured signals during special test routines.

Typical results are the determination of the

- Spring range,
- Closing force,
- Packing friction,
- Static characteristic,
- Dynamic behavior regarding the valve positioning by means of step-type changes in the reference variable,
- Operating range of the internal control signal (unit of air capacity),
- Closing and opening times.

A large part of the results are based on the measurement of the signal pressure in the actuator. This requires that the test runs be performed with the system shut down, i.e. off-line. Otherwise, i.e. on-line, only statements regarding the friction (essentially the packing) and the signal pressure level can be made [3; 7].

The static characteristic in the form of the adjusted output signal (valve position *x*) depending on the slowly and in small steps changed input signal (reference variable *w*), principally indicates the linearity, the tolerance band with an upper limit of 1 % for positioners, and the controllable valve position range. With digital positioners, this tolerance band can be adjusted very well with pilot valves via the dead band parameter (see section 5).

The analysis of the step response and the time constants until 63 % or 98 % of the new valve position (0 % old set point) are reached, provides information about the dynamic characteristics of the control loop, but not about where possible faults are located or about changes of individual control valve parameters.

Such systems are based on a convenient calibration or service of control valves off-line when the system is shutdown or in bypass operation, without the need for disassembly from the system ("transferring the shop to the field").

This concept has been adopted for control valves with digital positioners. Their temperature and signal pressure sensors are integrated in the positioner, e.g. as with advanced diagnostic functions in FIELDVUE by *Fisher Controls*. The existing sensors and analyses, however, are used only to supplement status data (see section 6.2). The proper analysis of the results for maintenance and repair recommendations as well as the preventive monitoring and recognition of faults require an expert for evaluation. Automatic diagnosis is not possible.

A different approach *without additional sensors* that always involve the risk of hardware failure and increased costs, results from the "intelligent" analysis of the signals exclusively required for positioning, such as

- the reference variable *w* as input signal,
- the controlled variable *x* for the valve position,
- the internal control signal *Y* as control algorithm output, see sections 3 and 5.

This approach especially uses control loop dynamics.

Special step responses to small input signal changes of max. ± 3 % and no mean value to cause as little

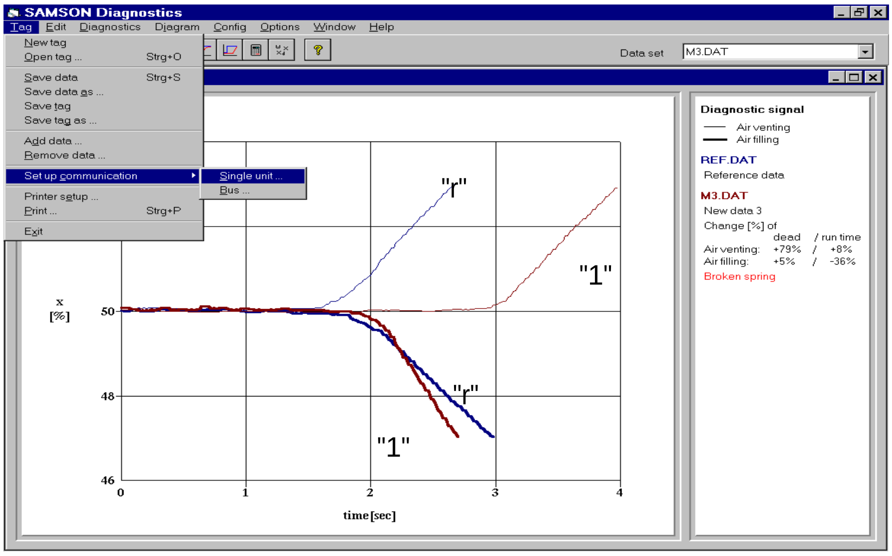


Fig. 10a: Diagnosis of spring failure (see text for comments)

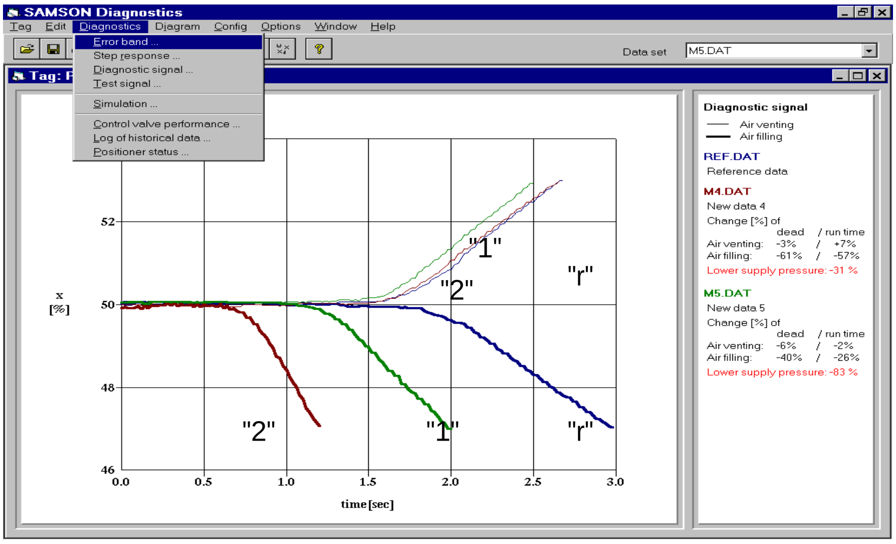


Fig. 10b: Diagnosis of air supply pressure changes (see text for comments)

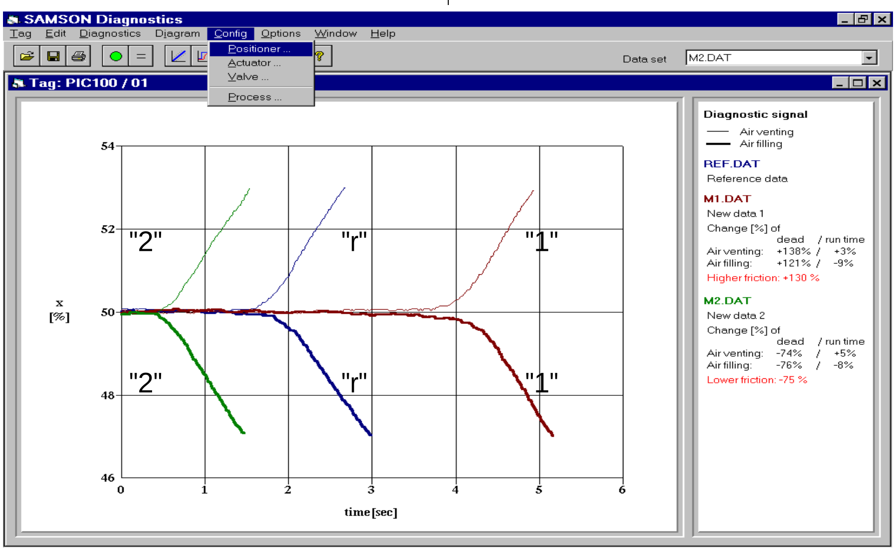


Fig. 10c: Diagnosis of changed friction (see text for comments)

Table 1: How the changing of important control valve parameters influences delay and run time

Parameters ++: increases considerably, +: increases, 0: practically no change, –: decreases, –: decreases considerably	Delay time/Run time *Venting*	Delay time/Run time *Filling*
Friction higher	+/0	+/0
Air supply	0/0	±/±
Spring failure	++/+0	+0/–
Air filter contamination	–/–	++/++
Closing force smaller	–/	–/
Leakage in actuator	–/–	++/++ with instability

process disturbance as possible are used as special diagnostic or test signals, with the internal control signal *Y* being adjusted to constant positioning rates. A comparison between the resulting actual signal value and the reference signal values enables the recognition of important control valve parameter changes (Figs. 10 a, b, c, and Table 1).

The time following a step change in the input signal at time zero until the turning point of the valve position direction is reached is called *delay time*. The *run time* must be understood as the time per valve position change (reciprocal value of speed).

Based on Table 1, changes of important control valve parameters can be recognized and possible faults detected:

- Hysteresis (friction, jamming of seat),
- Seat load (contact force too low),
- Spring range (not adjusted, spring failure),
- Air supply pressure (too low),
- Leakage of pneumatic system,
- Contamination of air filter,
- Pressure difference on the valve,
- Flow rate.

Figs. 10a, b, c show the new SAMSON diagnostic software for digital positioners. The examples show diagnostic tests performed at different times/states for a control valve with single-acting actuator and fail-safe position "Actuator spring opens valve". The curves marked "r" represent the reference condition prior to start-up of the system. The diagnostic signal is basically a step response with a nearly constant travel time of the valve stem and is picked up for both filling (bold line) and venting (thin line) of the actuator.

Comments on Fig. 10a

Curve "1" for venting shows that the delay time has increased by 79 % at nearly the same run time. While the actuator is filled with supply air, the run time decreases by 36 % and the delay time remains nearly the same. The rare case of a *spring failure*, however, shifts the balance of forces in the actuator. This causes higher lateral forces to act on the valve stem which in turn increase the static friction in the actuator and valve seals so that static and sliding friction keep alternating during the venting action. During the filling action, the movement is more continuous so that the delay time changes only very little. Due to the low pressure level in the actuator, the air supply capacity increases while the supply pressure remains constant so that the run time decreases a little.

Comments on Fig. 10b

Here, only during the filling action can changes be seen which indicate other conditions of the positioner's *compressed air supply*. Due to the internal transfer behavior in the positioner, starting with the control signal of the control algorithm up to the air supply capacity into the actuator, there is a higher air supply capacity when signal changes (small control signals) occur slowly at decreasing air supply pressure which results in smaller delay and run times.

Comments on Fig. 10c

Case "1" indicates that the delay time increased for the filling as well as for the venting (by 130 % on the average) while the run time remained nearly unchanged. According to Table 1, this indicates increased *friction*, i.e. packing friction, probably as a result of the tight stuffing box adjustment. In case "2", the friction decreased after some operating time, because again only the delay time clearly decreased for filling and venting (75 % on the average). Increased friction in zero range only may be due to jamming of the plug in the seat because of wear, deposits or mechanical damage. Changes over the entire range of the manipulated variable are probably due to a higher or lower packing friction as described above.

For the tightness of classic stem seals in the form of real packings, a minimum of friction as evidence for a sufficient force acting against the valve stem is certainly *required*. However, it is by no means sufficient, because in the case of groove wear, for instance, the average force acting against the stem and being distributed over the stem diameter only has a small effect on the tightness of the valve stem seal, so that the packing leaks. In addition, up-to-date, self-adjusting packings are characterized by significantly lower friction values at minimum equally high contact force [8]. For metal bellows seals of the highest valve stem sealing quality which are mostly used today, the friction values have absolutely no significance regarding the tightness. Therefore, leakage monitoring requires additional sensors in the form of gas detectors or pressure switches for all medium types. The switching function can be combined with the binary input of digital positioners (see section 6.2) which is propagated by many manufacturers. Control valves with double sealing systems (2 stuffing boxes or bellows/stuffing box) have long been available. They feature a test connection between the two seals, e.g. for a pressure switch.

If the diagnostic system described above is connected to a mathematical simulation model in the time range, the absolute size of the individual parameters can be calculated (identification). This requires, however, an accurate mathematical description of the positioner's mass flow behavior determined by manufacturer's measurements as well as known valve and actuator data. Due to the non-existent piping factor, this supplementing method can be applied especially for integrated positioner attachment.

In principle, the utilization of signals that already exist for process automation presents additional possibilities for fault diagnosis. For example, the calculated flow rate (pressure difference on the valve from diagnostic signal in combination with flow rate characteristic) can be compared to the directly measured flow rate (measuring signal) for detection of possible wear on seat and plug without zero shift, but with an already changed flow characteristic [7]. Fieldbus systems are especially suited to this method, because the individual field devices (sensors and actuators) are also capable of communicating with each other.

In addition, the mathematical model with its specifications and empirically established values, e.g. friction, as input parameters is suited to provide the user with an idea of what type of control valve behavior with respect to dynamics, time, etc., must be generally expected. This approach focuses more on the comparison between reality and expectation. A true fault diagnosis through identification of parameters in standard control operation is made impossible by the complexity of the system positioner, actuator and control valve, and by the usually not sufficient dynamic excitation in standard process operation.

7. Summary and prospects

Compared to conventional analog positioners, digital positioners provide the following advantages:

- Remote control including communication capabilities (HART/PROFIBUS-PA),
- Automatic start-up plus additional configuration options without iterative adjustment of zero and span,
- Self-optimization and supervision of the positioner's control loop,
- Control valve monitoring.

Maintenance and repair options are thus expanding and the process plant reliability improves. The entire control valve monitoring process can be divided in three phases:

- Initialization during automatic start-up,
- Status requests plus alarm signals, and
- Detailed fault diagnosis.

Positioning systems that are currently available on the market, though, do not enable detailed fault observation and analysis during process operation, despite the application of additional sensors. A detailed and clear analysis of the positioner's condition including instructions and recommendations for maintenance and repair cannot be provided.

However, this can be realized only with the help of the sensors required for positioning anyway, and, in particular, by recording the control loop dynamics through evaluation of small diagnostic test signals with no mean value at short and little process disturbances so that all important control valve parameters can be monitored and determined on-line. Remarkable are the clear statements without the necessity for consulting an expert.

It should be interesting to see which positioner faults are found most often in process engineering plants employing this type of fault diagnosis software. In connection with this, a prominent user of control valves in the large-scale chemical industry is currently conducting a statistical investigation. However, a large part of critical control valve conditions will most certainly be significantly reduced alone through self-adjusting, integrated, digital positioners without the utilization of additional diagnostic options.

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