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Monitoring and Diagnostics of Control Valves using the "VlvMon" Function Block in SIMATIC PCS 7

SIMATIC PCS 7 Condition Monitoring Library

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Preface

Objective of the Application

The objective is performance monitoring and diagnostics of control valves in the context of SIMATIC PCS 7 plant asset management. A low-cost solution can be achieved by intelligent combination and logical interpretation of measured process values which are (mostly) already available in the DCS, in contrast to highend condition monitoring systems based on dedicated additional sensors, e.g. vibration sensors or structure-borne sound sensors.

Main contents

The following issues are discussed in this application:

- How to implement valve monitoring.

- How to parameterize and commission valve monitoring.

- How to evaluate the monitoring results in the context of plant asset management.

Validity

Valid for PCS 7 V8.0 Update 1 and later versions.

NOTE	Please make sure you observe the notes of Condition Monitoring Library. Read the notes carefully, because they contain information on installing and using Condition Monitoring Library.

Table of contents

1 Introduction Valve Monitoring

1.1 Area of Application

The PCS 7 Add-on product VlvMon offers a cost-effective solution for monitoring and diagnosis of control valves, i.e. valves that can be fully or partially opened or closed by continuous valve position control. Valve monitoring is based on an intelligent combination and logical interpretation of measured process values which are already available in the DCS. The VlvMon complements the self-diagnosis of an electro pneumatic positioner, such as SIPART PS, or completely replaces this if the positioner does not offer any self-diagnosis, or the self-diagnosis is not integrated into the DCS.

Valves just like pumps are one of the most common actuators in process plants. They are affected by different signs of wear and tear, such as wear (abrasion, cavitation, corrosion) or fouling (material caking, build-up) on valve cone and/or valve seat. The valve behaviour can be described by a static valve characteristic at runtime. Valves are mechanical assets which are not registered as field devices in the DCS by themselves, similar to pumps. Typically, they are driven pneumatically and combined with an electro pneumatic positioner. The positioner as an intelligent field device is already embedded into the asset management of the DCS. The condition of the valves has a significant influence on the availability and safety of the complete plant. The VlvMon permits a condition oriented monitoring of control valves with different process values. Valve malfunctions and future valve failures can be recognized early by this monitoring approach. This allows for an improved maintenance planning and contributes to increase the availability of the complete plant.

The function VlvMon is applied to

- provide warnings against potential valve damage due to unfavorable operating conditions or violation of wear limits: permanent operation without valve standstill, permanent standstill, i.e. operating hours without any valve movement inducing danger of material caking, violation of maximal number of strokes, violation of maximal number of shifts in directions, violation of operating hours limit.

- provide early detection of developing valve degradation: material caking or deposits, wear, monitoring of reaction times and flow characteristics.

- optimize valve design in the long term by means of statistical analysis of operating data: histogram of valve positions.

The VlvMon function block can be applied for any control valve which can be opened/closed continuously. Binary switching valves (fully open/close only) are not subject of this consideration. Only the basic condition monitoring (monitoring of operating hours, valve standstill, etc.) is performed if the valve cannot read back the actual valve position (valve position feedback). Control valves with position feedback permit a check on valve movement errors (wear, material caking etc.). If there are additional process values available which are typically measured in the environment of valves, an extended valve diagnosis can be performed (monitoring of the valve characteristic, the supply pressure etc.).
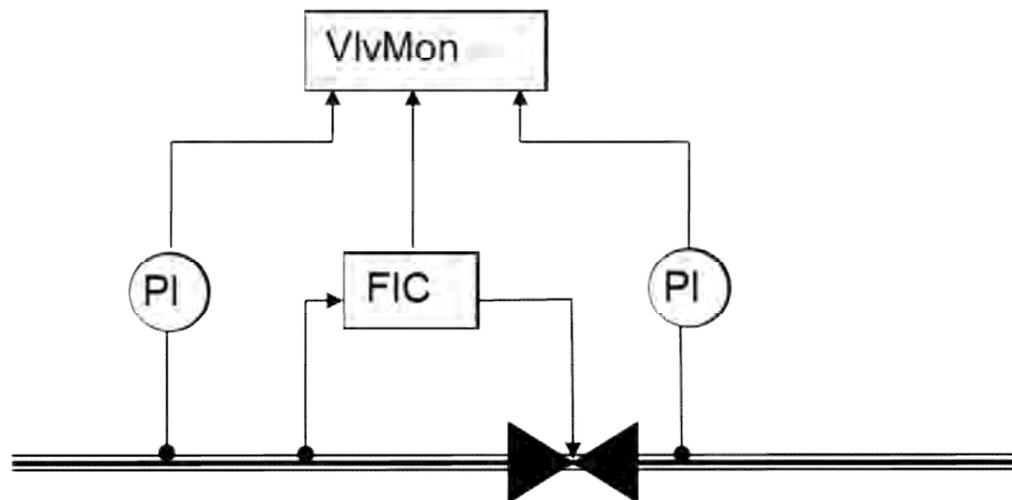
Relevant process values in the environment of valves:

- flow rate of medium
- valve intake pressure
- valve outlet pressure
- valve position setpoint

- valve actual position (position feedback)
- pressure of compressed air supply

Figure 1-1: P&I-diagram of valve with associated sensors and actors incl. valve monitoring

The VlvMon function block does not include its own messaging, but can be linked with PCS 7 standard messaging function blocks.

VlvMon can inform operators on any violations of the valve operating range and on deviations from the expected characteristic, and make this data available for further processing via the block outputs.

The block itself is designed purely for diagnostic purposes and, as such, does not intervene directly in the operation of the control valve. This means that it can be deployed, or even retrofitted, without the risk of affecting the process. If required, active intervention can be achieved by evaluating the block outputs.

1.2 Functions

The VlvMon function block offers the following functions (literature /1/):

- Analysis and graphical representation of characteristics of valve data and operation states
- Diagnostic functions for any control valve
- Diagnostic functions for control valve with valve position feedback
- Extended diagnostic functions with additional sensors

1.2 Functions

1.2.1 Analysis and Graphical Representation of Characteristics of Valve Data and Operation States

- Reference flow characteristic: display of reference flow as a function of valve position with normalized flow (flow converted to norm difference pressure), display of actual operating point and relative/absolute deviation of operating point from reference characteristic line.

- Actual flow characteristic: display of actual flow as a function of valve position with normalized flow to detect drift, calculation of relative deviation of actual flow characteristic from reference characteristic line.

- Reference response time characteristic: display of reference valve response time as a function of step height for positive setpoint steps only, display of actual operating point and relative/absolute deviation of operating point from reference characteristic line.

- Actual response time characteristic: display of actual valve response time as a function of step height for positive setpoint steps only to detect drift.

- Histograms: statistical evaluation of valve operating states with respect to valve positions.

1.2.2 Diagnostic Functions for any Control Valve

The function block offers the following basic diagnostic functions for warning operators in case of unfavorable operating states and reaching of wear limits. These diagnostic functions do not identify any valve faults in the narrow sense. These functions, however, help to prevent valve failures. They allow for an improved maintenance planning and detect if a valve has exceeded its life cycle:

- Monitoring of maximal operating hours in permanent standstill without any valve movement → material caking, deposits, build-up.

- Monitoring of maximal operating hours in permanent operation without valve standstill → overload.

- Monitoring of maximal number of strokes → maintenance.

- Monitoring of maximal shifts in directions → maintenance.

1.2.3 Diagnostic Functions for Control Valve with Valve Position Feedback

The function block detects a faulty valve movement by the following diagnostic methods. The setpoint provided by the positioner is compared to the real position feedback of the valve. This way one can detect wear, build-ups, stiffness, increased friction and other valve movement faults:

- Detection of valve movements without setpoint demand→ compressed air leakage.

- Displacement of upper and lower end position → damage to valve cone, zero offset displacement.

- Detecting of a steady state control error after end of valve movement → indication of drive problems or supply voltage problems.

- Monitoring of valve response time with respect to a reference response time characteristic → stiffness, damage of valve drive.

- Monitoring of time period (dead time) which is needed by control valve to leave a specified tolerance band (dead zone) → material caking, stiffness.

1.2.4 Extended Diagnostic Functions with Additional Sensors

The function block offers the following extended diagnostic functions if additional sensors are available, which are already installed in the environment of valves in many cases:

- Additional intake and outlet pressure sensor and flow sensor:
  - Monitoring of flow operating point with respect to a reference flow characteristic as a function of valve position → indication of variation of valve cross-sectional area (flow capacity) due to material caking or abrasion.
  - Comparison of actual flow characteristic with reference flow characteristic for a long-term drift detection → mechanical damage at the valve cone, material caking, abrasion.

- Additional compressed air supply sensor:
  - Monitoring of air pressure → leakage in compressed air supply.

1.2.5 Teach Function

- Point wise teaching of reference flow characteristic via coordinates of interpolation points in reference state of the valve.
- Point wise teaching of reference response time characteristic via coordinates of interpolation points in reference state of the valve.

1.3 Typical Application Examples

- Control valves that show malfunctions and signs of wear more frequently than the average.
- Control valves that are in danger of cavitation.
- Control valves where chemical fouling occurs.
- Control valves that show unaccountable variations with respect to reference flow and response time characteristics.

2 Implementation of Valve Monitoring

2.1 Installation of SIMATIC PCS 7 Add-on Product

The installation of the PCS 7 Condition Monitoring Library (CML) is carried out by the standard setup program.

The list bellow shows available combination of PCS 7 and Condition Monitoring Libraries.

Table 2-1

PCS 7 version	CML version	Link
PCS 7 V8.0 Upd.1	Condition Monitoring Library V8.0	http://support.automation.siemens.com/WW/view/en/70081830
PCS 7 V8.0 SP1	Condition Monitoring Library V8.0+SP1	http://support.automation.siemens.com/WW/view/en/82647049

After installation the library is visible as "Condition monitoring" in the S7 library catalogue.

With the installation the manual and online help are integrated too.

2.2 Configuration

With respect to engineering, two completely different use cases are discussed: retrofitting valve monitoring in a running plant, or greenfield engineering of the complete automation around a control valve incl. valve monitoring.

2.2.1 Engineering of the Complete Automation (Based on Solution Template)

Control valves are among the most frequent actuators in process plants just like pumps. Around control valves, there is a typical combination of actors and sensors that together with the valve provide the equipment module "control flow of a fluid and monitor it".

Pump Unit

Since valves are frequently operated in combination with fixed speed pumps, the valve is often already a component in the equipment module belonging to the pump and therefore also a component of the Pump Unit (literature /2/). The typical control and interlock functions which are required in the same way for all pumps as well as the pump monitoring are part of the automation of the Unit. The valve monitoring with the VlvMon function block can be implemented as an extension of the Pump Unit.

In addition to the flow indication for the flow control, the pressure indications in front of and behind the pump and the temperature indication of the liquid medium, a pressure indication at the valve outlet is realized.

It is recommended to extend the solution template Pump Unit by valve monitoring in the library part of the PCS 7 project.

2.2 Configuration

Process Tag Type Flow Control

If there is already a control module type for flow control according to Figure 1-1 in the project, it makes sense to integrate the VlvMon function block into this template, because both valve position (=manipulated variable of flow controller) and flow (=controlled variable of flow controller) are already available here.

Parameterization of Flow Controller based on Valve Characteristic and Valve Transit Time

If the sensor time constant T_1 of the flow measurement, the valve transit time T_m (from end position to end position) and the valve characteristic (of which only the maximal gradient K is relevant) are known from the VlvMon, the parameter of a PI flow controller

$$K_r(s) = G_{ain}(1 + \frac{1}{T_I s})$$

can be calculated beforehand, and a commissioning with the PID tuner is no more necessary. The sensor time constant is typically specified by SIMATIC PDM at the sensor. The valve transit time is measured by the positioner Siemens SIPART PS2 in the context of its controller self-tuning and is readable in PDM.

Controller parameters:

Reset time $T_I = T_1$ (pole compensation)

Gain $G_{ain} = \dfrac{5T_1}{4T_m K}$ (aperiodic limit case for a 20% step in valve position, typically

this value can still be intensified a little bit.)

Compensation of nonlinear characteristics

If the valve characteristic anyway is learned in the context of valve monitoring and it shows a strongly nonlinear behavior, the control performance can be improved by a compensation of this static nonlinearity by a polygon function block.
Note: Nonlinear operating characteristics which are relevant for control can appear even in the context of "linear" valve characteristics according to the data sheet.

2.2.2 Retrofitting of Valve Monitoring in a Running Plant

In the following it is assumed that there is the basic automation around the control valve incl. flow control already in the PCS 7 project.

The function block VlvMon is inserted in a CFC chart in the appropriate folder of the technological hierarchy. Because VlvMon connects sensor signals from different measurement tags, you will typically generate a new chart for it. This chart can be located in the hierarchy folder to which the valve belongs, or in a separate hierarchy tree "plant diagnosis". In this hierarchy tree similar to the PCS 7 maintenance station, target group specific information could be collected and displayed. While the maintenance station is targeted to maintenance personal, the target group for "plant diagnosis" are plant managers, process and control engineers, who are responsible for optimizing plant operation.

2.2.3 CFC Engineering

The VlvMon function block is inserted into the designated CFC via Drag&Drop from the block catalogue. The positioning of the function blocks in an OB (cyclic task) is depending on the positioning of the related analogue driver blocks for process values of pressure and flow. If the measuring of valve response times is urgently desired, then the analogue driver blocks for process values and the VlvMon function block should be inserted in the fastest possible OB. The other monitoring functions (characteristics, operating hours etc.) are not critical in terms of real-time. If the response times do not have to be monitored by the VlvMon, the function block can be inserted in a slower OB (e.g. OB30) to save CPU resources.

The function block requires the following process values for control valves with position feedback:

- flow ➔ input **Flow** [l/h]

- valve intake pressure ➔ input **P_In** [bar]

- valve outlet pressure ➔ input **P_Out** [bar]

- valve position setpoint ➔ input **MV** [%]

- valve actual position feedback ➔ input **Rbk** [%] (feedback position)

For the extended monitoring with an additional sensor:

- binary input variable for monitoring of compressed air supply ➔ input **SuppPress**

The process signals are linked with the related input variables of the analogue driver blocks.

For the monitoring of the flow characteristic the flow must be independent of the actual pressure conditions. Using the two pressure sensors in front of and behind the control valve the flow is standardized to a norm pressure difference. Otherwise a variation of the pump performance would cause the curve moving. The flow is divided by the root of the difference pressure to obtain the normalized flow rate F_{Norm} (see formula 2.1).

Formula 2.1: norm flow

$$F_{Norm}(A) = \frac{F(A, \Delta p)}{\sqrt{\Delta p}} = \alpha A \sqrt{\frac{1}{\rho/2}}$$

$F_{Norm} = normalized\ flow$
$F = flow$
$A = valve\ cross-section$
$\Delta p = pressure\ drop$
$\rho = density$
$\alpha = volumetric\ flow\ coefficient$

For the automatic learning of valve characteristics the SteadyState function block is required. The function block is provided together with the VlvMon function block in the same library.
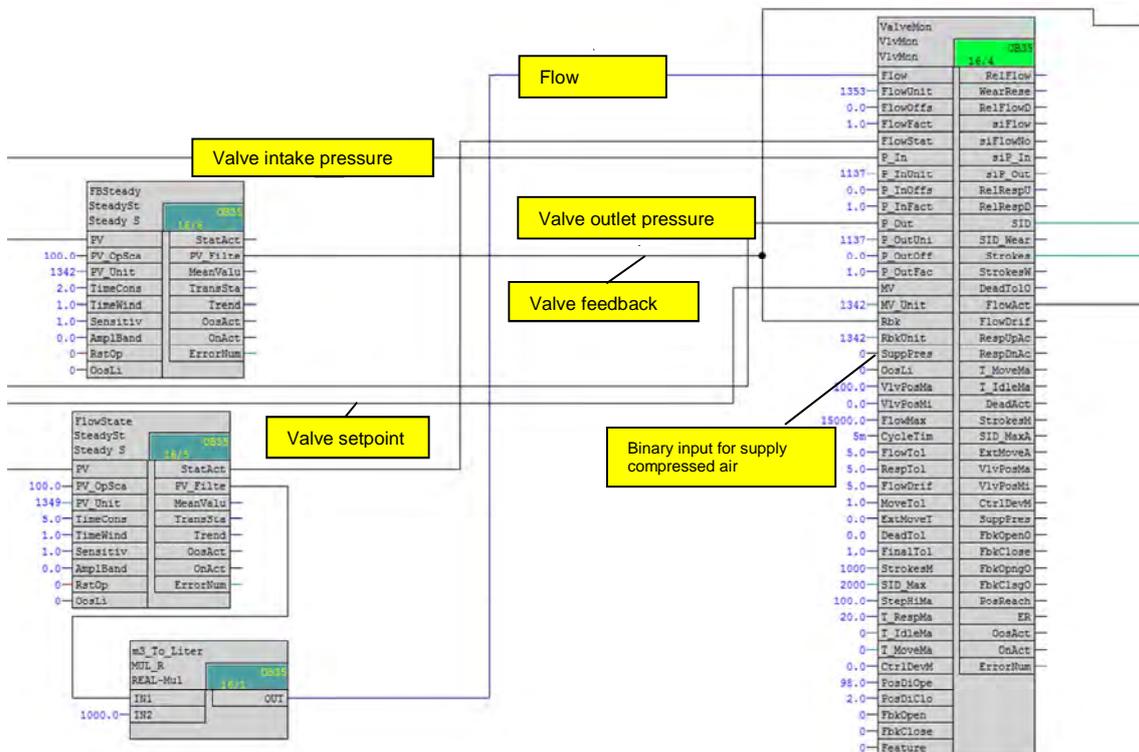
2.2 Configuration

The SteadyState function block is applied to detect steady states in a dynamic process. It analyses an input signal and decides without delay if this signal is in a steady state or not. Further information is provided in the online help of the SteadyState function block.

One instance of SteadyState function block is required for flow characteristic and response time characteristic to be monitored. Each of them has to be connected in the following way:

- for flow characteristic:
  Process value flow at analog driver block ➔ input SteadyState.**PV**
  output SteadyState.**PV_Filtered** ➔ input ValveMon.**Flow**

- for response time characteristic:
  Process value feedback position at analog driver block ➔ input SteadyState.**PV**
  output SteadyState.**PV_Filtered** ➔ input ValveMon.**MV**

Figure 2-1: Linking of VlvMon function block in CFC

3 Parameter Specification and Commissioning

3.1 Required Data for Control Valve

The technical data listed in the following sections are required for configuration of valve monitoring and have to be provided beforehand.

3.1.1 Data of Control Valve

- Maximal number of strokes
- Maximal number of shifts in directions
- Maximal flow through the valve
- Maximal standstill period without interruption
- Maximal permanent movement period without interruption

The VlvMon function block can automatically learn the flow- and response time characteristic during operation. If this is not possible because no significant valve movements are permitted in productive plant operation, the characteristics can be taken from manuals and entered manually (see figure 3-1).

3.2 Parameter Input in Faceplate or CFC

3.2.1 Operating data of Control Valve

The basic operating data of the valve are displayed in the faceplate, view "Default".

Figure 3-1: Operating data of Control Valve
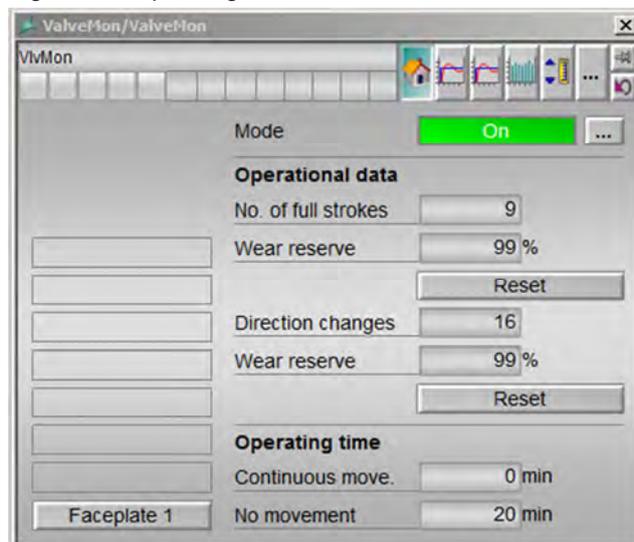
- Number of complete strokes ➔ **StrokesMax** (in faceplate, view „Default", or in CFC)
- Wear reserve of number of strokes ➔ **StrokesWearRes** (in faceplate, view „Default ", or in CFC)

3.2 Parameter Input in Faceplate or CFC

- Number of shifts in directions ➜ **SID_Max** (in faceplate, view „Default", or in CFC)
- Wear reserve of number of shifts in directions ➜ **SID_WearRes** (in faceplate, view „Default ", or in CFC)
- Standstill period without movement ➜**T_IdleMax** (in faceplate, view „Default", or in CFC)
- Permanent (continuous) movement period without interruption ➜ **T_MoveMax** (in faceplate, view „Default", or in CFC)

3.2.2 Parameters of Limit Values and Monitoring Tolerances

The parameters of monitoring tolerances and hysteresis areas are displayed in the faceplate, view "Limit values".

Figure 3-2: Parameters of limit values and monitoring tolerances
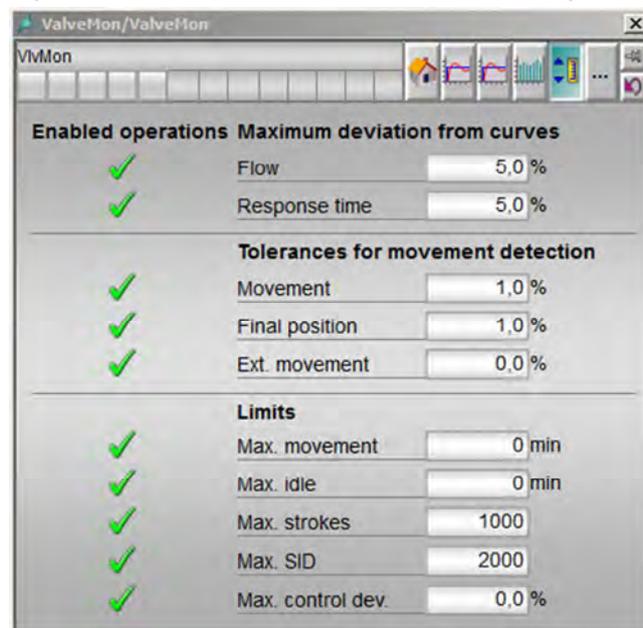
- Maximal deviation in [%] of the flow from the reference flow characteristic ➜ **FlowDriftTol** (in faceplate, view „Limit values", or in CFC)
- Maximal deviation in [%] of the response time from the reference response time characteristic ➜ **RespTol** (in faceplate, view „Limit values", or in CFC)
- Minimal position feedback variation in [%], which can be interpreted as a valve movement ("Movement") ➜ **MoveTol** (in faceplate, view „Limit values", or in CFC)
- Maximal tolerance in [%] of the valve position feedback relative to the valve setpoint ("Final Position") ➜ **FinalTol** (in faceplate, view „Limit values", or in CFC)
- Minimal feedback change in [%] without setpoint demand by DCS ("External movement") ➜ **ExtMoveTol** (in faceplate, view „Limit values", or in CFC)
- Minimal tolerance area, which control valve must leave in order to detect a valid valve movement ("Deadband") ➜ **DeadTol** (available in a later version)

3.2 Parameter Input in Faceplate or CFC

- Maximal number of strokes ➔ **StrokesMax** (in faceplate, view „Limit values", or in CFC)
- Maximal number of shifts in directions ➔ **SID_Max** (in faceplate, view „Limit values", or in CFC)
- Maximal flow through the valve ➔ **FlowMax** (CFC only)
- Maximal standstill period without interruption ➔**T_IdelMax** (in faceplate, view „Limit values", or in CFC)
- Maximal permanent movement period without interruption ➔ **T_MoveMax** (in faceplate, view „Limit values ", or in CFC)

If the alarm limits are violated at runtime, the related binary outputs of VlvMon function block are set to "true". Limit violation of:

- Number of strokes ➔ **StrokesMasAct** = 1
- Shifts in directions ➔ **SID_MaxAct** = 1
- Time without stillstand ➔ **T_IdleMaxAct = 1**
- Movement period ➔ **T_MoveMaxAct** =
- Deviation of flow ➔ **FlowAct** = 1
- Deviation of response time open ➔ **RespUpAct** = 1
- Deviation of response time close ➔ **RespDnAct** = 1
- Tolerance area of valve position feedback relative to valve setpoint ➔ **CtrlDevMaxAct** = 1
- Change of valve position feedback without setpoint demand ➔ **ExtMoveAct** = 1
- Deadband monitoring is started by **DeadActIn** = 1 and shown by ➔ **DeadAct** = 1 (available in a later version))

3.2 Parameter Input in Faceplate or CFC

3.2.3 Parameters of Characteristic Lines

The flow and the response time characteristic respectively consist of 15 interpolation points. If the characteristics are available from the data sheet, significant interpolation points can be listed in the faceplate, view "Parameter 1". The interpolation points are connected with each other by linear interpolation and displayed in the faceplate.

Figure 3-3: Interpolation points of flow characteristic, Parameter 1

ValveMon/ValveMon

VlvMon

Flow characteristic

|	Valve position %	Flow L/h
1	5,0	0
2	10,0	778
3	15,0	1045
4	20,0	1170
5	25,0	1624
6	30,0	1947
7	35,0	2456
8	40,0	2805
9	45,0	3771
10	50,0	4619
11	55,0	6314
12	60,0	7261
13	65,0	8081
14	70,0	11381
15	75,0	14978
16	80,0	256
17	85,0	289
18	90,0	324
19	95,0	361
20	100,0	400
Max		15000

Manual Parameter Input of the Flow Characteristic:

- Interpolation points of valve position feedback (X-axis: [%]) ➔ **VlvPos1-VlvPos20**(in faceplate, view „Parameter 1", or in CFC)

- Interpolation points of normalized flow rate (Y-axis: [l/h]) ➔ **Flow1 ... Flow20** (in faceplate, view „Parameter 1", or in CFC)

- Maximal valve position feedback for scaling of the X-axis ➔ **VlvPosMax** (in faceplate, view „Parameter 1", or in CFC)

- Maximal flow rate for scaling of the Y-axis ➔ **FlowMax** (in faceplate, view „Parameter 1", or in CFC)

3.2 Parameter Input in Faceplate or CFC

Figure 3-4: Interpolation points of reaction time characteristic, Parameter 2
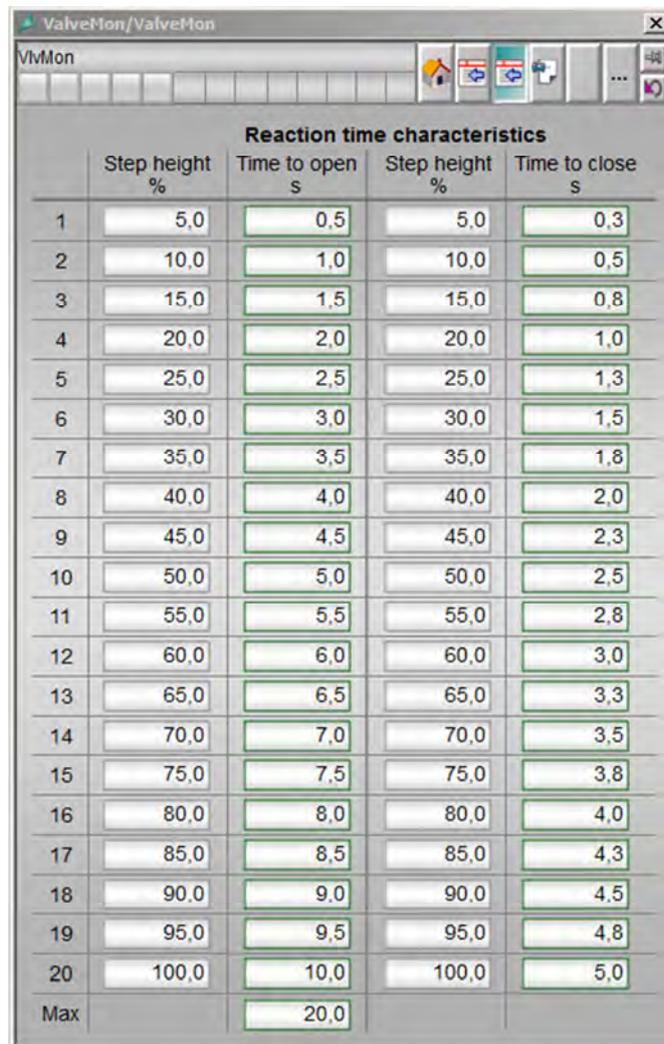
|	Step height %	Time to open s	Step height %	Time to close s
Reaction time characteristics				
1	5,0	0,5	5,0	0,3
2	10,0	1,0	10,0	0,5
3	15,0	1,5	15,0	0,8
4	20,0	2,0	20,0	1,0
5	25,0	2,5	25,0	1,3
6	30,0	3,0	30,0	1,5
7	35,0	3,5	35,0	1,8
8	40,0	4,0	40,0	2,0
9	45,0	4,5	45,0	2,3
10	50,0	5,0	50,0	2,5
11	55,0	5,5	55,0	2,8
12	60,0	6,0	60,0	3,0
13	65,0	6,5	65,0	3,3
14	70,0	7,0	70,0	3,5
15	75,0	7,5	75,0	3,8
16	80,0	8,0	80,0	4,0
17	85,0	8,5	85,0	4,3
18	90,0	9,0	90,0	4,5
19	95,0	9,5	95,0	4,8
20	100,0	10,0	100,0	5,0
Max		20,0		

Manual parameter input of the response time characteristic:

- Interpolation points of the step height close (X-axis: [%]) ➔ **StepHiDn1 ... StepHiDn20** (in faceplate, view „Parameter 2", or in CFC)

- Interpolation points of the step height open (X-axis: [%]) ➔ **StepHiUp1 ... StepHiUp20** (in faceplate, view „Parameter 2", or in CFC)

- Interpolation points of the response time close (Y-axis: [s]) ➔ **RespDn1 ... RespDn20** (in faceplate, view „Parameter 2", or in CFC)

- Interpolation points of the response time open (Y-axis: [s]) ➔ **RespUp1 ... RespUp20** (in faceplate, view „Parameter 2", or in CFC)

- Maximal step height for scaling of the X-axis ➔ **StepHiMax** (in faceplate, view „Parameter 2", or in CFC)

3.2 Parameter Input in Faceplate or CFC

Flow Characteristic

The flow characteristic is displayed in the faceplate, view „Flow characteristic". The reference flow characteristic (flow rate as a function of the valve position) is shown for flow monitoring as a solid line (see Figure 3-5). The interpolation points of the reference characteristic can be entered manually or teached automatically. The scaling of the coordinate axis is done by the input variables **FlowMax** (flow) and **VlvPosMax** and **VlvPosMin** (valve feedback position) in faceplate, Parameter 1", or in CFC. The indication of the actual characteristic learned automatically (dotted line) can also be displayed in the diagram beside the reference characteristic. By setting the input variable **AdoptActFlow** = 1 (in faceplate, view „ Flow characteristic ", or in CFC) the actual characteristic is adopted to be the reference characteristic. This should be done in good condition of the valve after sufficient data have been collected in the relevant operating area of the flow such that the current characteristic has an adequately smooth shape and covers an adequately broad area.

Figure 3-5: Flow characteristic, green dot: current operating point

3.2 Parameter Input in Faceplate or CFC
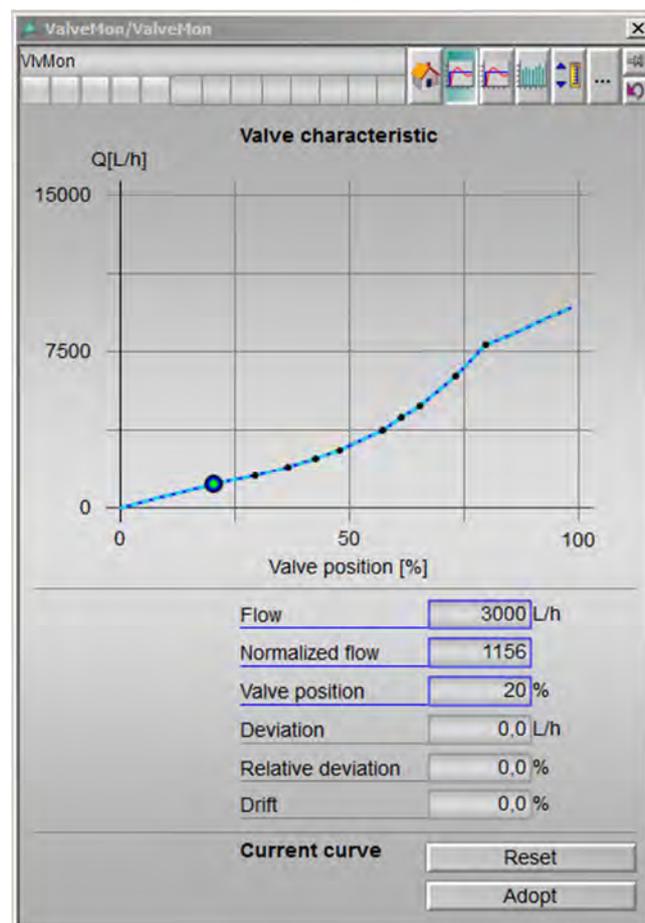
Operating Point Monitoring

In order to diagnose damages inside the valve the reference flow characteristic is compared with the actual operating point (*Flow* or *siFlowNorm* and *Rbk*) and the actual characteristic learned automatically. If the deviation of the operating point from the reference curve is within the tolerances, the operating point is green in the diagram. Otherwise a deviation outside the tolerance limits is shown by a red operating point (see Figure 5-3).

Deviations from the reference characteristic can be explained by a variation of the valve cross-section. Mechanical damages and material caking inside the valve cause deviations of the valve cross-section. These result in a different flow at the same valve position. If the actual operating point is below the characteristic, the actual flow is too small with respect to the valve position and there is e.g. a material caking or blockage. If the actual operating point however is above the characteristic, material is missing inside the valve. The reasons for this can be material loss by abrasion, cavitation, rust or breaking of the valve cone.

The operating point monitoring recognizes a temporary deviation of the reference characteristic and displays both the absolute deviation (*DevFlow*) and the relative deviation (*RelFlow*). During a violation of the maximum relative deviation (*FlowTol*, in faceplate, view „tolerance", or in CFC) the output value *FlowAct* is set.

Automatic Learning of the Characteristics

The automatic learning of the characteristics is always active. The function block monitors the different input variables and detects new steady state measurements. These new measurements are used to obtain an actual characteristic as up-to-date as possible. The learned flow characteristic consists of 20 interpolation points (*ActFlow1, ActVlvPos1*) ... (*ActFlow20, ActVlvPos20*). Each interpolation point is calculated from up to 5 measurements. The influence of single outliers and measurement inaccuracies is reduced by this averaging.

The averaging is weighted by the actuality of the single measured values. New measured values are weighted more heavily than obsolete values. The actuality of the interpolation points is shown in the diagram (see Figure 3-6) by the respective point size. Large points are a sign for high actuality of the measured values. If a valve position was not yet reached and no corresponding measured value is available for this point, this point is calculated by a linear interpolation of the surrounding points. The actuality of the value and the related point size are set to the minimum value. With the binary input variable *Adopt_ActFlow* =1 respectively the button "Adopt" in view "Flow characteristic" the actual characteristic is adopted to become the reference characteristic.

3.2 Parameter Input in Faceplate or CFC

Figure 3-6: Teaching of reference flow characteristic
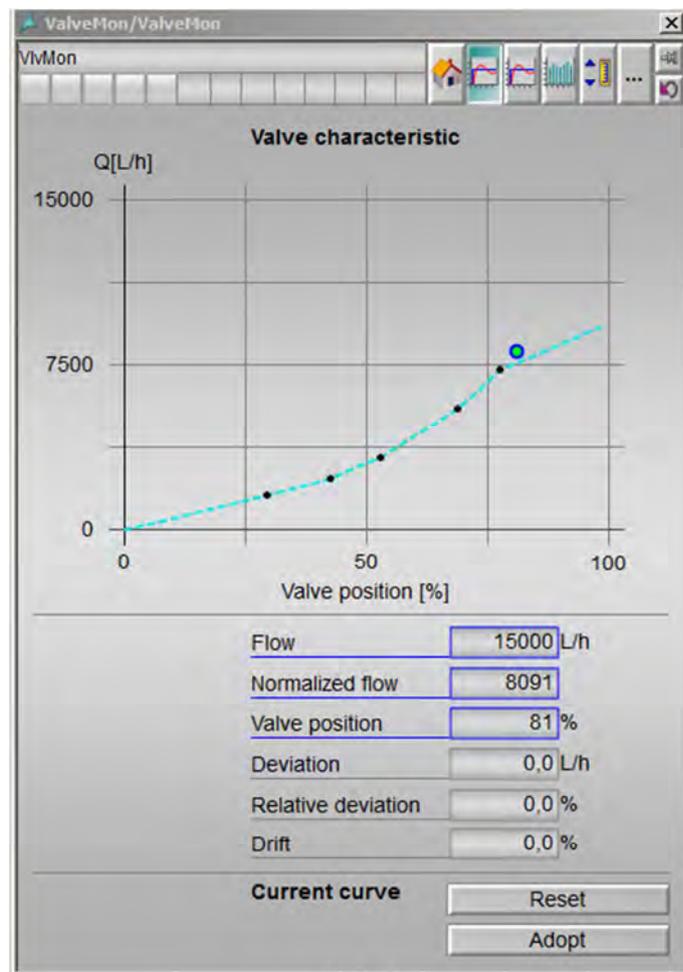
If there are no interpolation points for the reference characteristic, the current actual characteristic can be adopted to become the new reference characteristic (**Adopt_ActFlow** = 1). Single interpolation points of the actual characteristic can also be used for readjustment of the reference characteristic. If the actual characteristic is to be learned from scratch, the current actual characteristic has to be deleted (**RstActFlowOP** = 1 in CFC, or in faceplate, view „Flow characteristic").

Drift Detection

The automatic learning of the characteristics provides the basis for long-term drift detection. Long-term deviations can be identified this way, better than by simple operating point monitoring. It can be decided whether the characteristic as a whole drifts away or the behavior differs only in certain areas of the characteristic line. The monitoring of the drift detection compares the reference characteristic with the actual characteristic learned automatically. The function block calculates the area between the two curves and displays the relative deviation to the reference characteristic at the output variable **DevFlow**. If the deviation between the two curves exceeds the tolerance **FlowDriftTol**, the output variable **FlowDriftAct** is set.
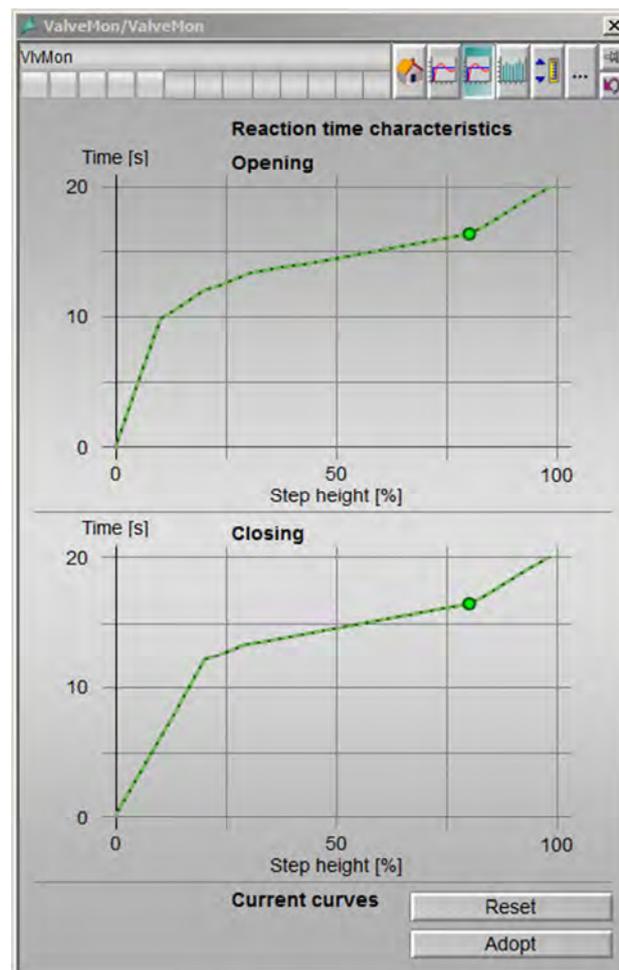
3.2 Parameter Input in Faceplate or CFC

Response Time Characteristics

The response time characteristic is displayed in the faceplate, view „Response characteristic". The response time is the time which a valve needs to reach the valve position setpoint. The reference response time characteristic (response time as a function of the step height) is shown as a solid line. The interpolation points of the reference characteristic can be entered manually or learned automatically. The scaling of the coordinate axis is related to the input variables *T_RespMax* (response time) and *StepHiMax* (step height) in faceplate, view „Parameter 2", or in CFC. The actual characteristic learned automatically (dotted line) can be displayed in the diagram besides the reference characteristic. The response time is also depending on the direction of valve movement. The characteristic for positive setpoint steps can differ from the characteristic for negative setpoint steps. The reason is that valves are typically moved in one direction by compressed air and in the other direction by spring force. These two drive systems react differently to faults and valve damages. The response times for opening and closing are therefore included in separate characteristics.

| NOTE | The function block recognizes only real setpoint steps, no other signal forms, such that the response time monitoring does not provide any meaningful results if monitoring a valve operated by a flow controller in automatic mode. |

Figure 3-7: Response time characteristic

3.2 Parameter Input in Faceplate or CFC

- Operating Point Monitoring:

  In order to diagnose damages of the valve drive or friction problems in the valve sealing the reference response time characteristic is compared to the actual operating point (*StepHiDn, T_RespDn* for closing and *StepHiUp,TRespUp* for opening) and an actual characteristic learned automatically. If the deviation of the operating point from the reference curve is within the tolerances, the operation point is green in the diagram. Otherwise a deviation outside the tolerance limit is shown by a red operating point.

  A slow valve movement results in a large response time since the valve needs a long time to reach the end position. An increasing response time can be an indicator of increased friction inside the valve. Moreover, a leakage of the compressed air supply results in slowing down valve movements. A damage of the valve drive can also be a reason for deviations of valve response time.

  The operating point monitoring recognizes a temporary deviation of the reference characteristic and displays both the absolute deviation (*DevRespDn* and *DevRespUP*) and the relative deviation (*RelRespDn* and *RelRespUp*). During a violation of the maximum relative deviation (*MoveTol*, in faceplate, view „tolerance", or in CFC) the output value *RespDnAct* and *RespUpAct* is set.

- Automatic Learning of the Characteristic:

  The automatic learning of the characteristic is always active. The function block monitors the different input variables and detects new steady state measurements. These new measurements provide the data to obtain a characteristic as up-to-date as possible. The response time characteristic learned automatically consists of 15 interpolation points (*ActStepHiDn1, ActRespDn1*)... (*ActStepHiDn20, ActRespDn20*) and (*ActStepHiUp1, ActRespUp1*)... (*ActStepHiUp20, ActRespUp20*). Each interpolation point is formed from up to 5 measurements. The influence of single outliers and measurement inaccuracies is reduced by this averaging.

  The averaging is weighted by the actuality of the single measured values. New measured values are weighted more heavily than obsolete values. The actuality of the interpolation points is shown in the diagram by the related point size. Large points are a sign of a high actuality of the measured values. If a certain setpoint step height was not yet observed and no corresponding measured values are available for this point, this point is calculated by linear interpolation from the surrounding points. The actuality of the value and the related point size are set to the minimum value.

  If there are no interpolation points for the reference characteristic, the current actual characteristic can be adopted to be the new reference characteristic (*Adopt_ActResp* = 1 in CFC, or in faceplate view „Response characteristic"). Single interpolation points of the actual characteristic can also be used for readjustment of the reference characteristic. If the actual characteristic is to be learned from scratch, the current actual characteristic has to be deleted (*ActRespReset* = 1, in faceplate, view „Response characteristic", or in CFC).

3.2 Parameter Input in Faceplate or CFC

- Deadtime:

  The deadtime is also an important parameter of the valve movement, besides the response time. The dead time is the time which the valve needs to get into movement. If the dead time increases, this is an indicator of material caking or stiffness of the valve. For the measuring of the dead time a tolerance range (**DeadTol**, in faceplate, view „Tolerance", or in CFC) is defined around the actual valve position. If the position setpoint changes, a timer is started. The timer measures the time which passes until the valve position has left the dead zone (**DeadTolOut**). If the deadtime exceeds the tolerance band, the output variable **DeadAct** is set. (Available in a later version).

- Control Error:

  If the valve has completed its movement, the final position is compared to the reference position. The difference is the steady state control error. A remaining error indicates problems with the drive, with the supply energy or a mechanical damage. If the control error exceeds the tolerance band (**FinalPos**, in faceplate, view „Tolerance", or in CFC), the output variable **CtrlDevMaxAct** is set.

3.2 Parameter Input in Faceplate or CFC

3.2.4   Histograms

The histograms visualize the frequency distribution of the different valve positions or step heights over the complete valve position range (0...100%) as a bar chart. The range is divided into ten bars, each of which represents one 10% interval, i.e. the valve position range (X-axis) is subdivided into 10 part sections equal in size. Every part section has a counter of its own. The first part section e.g. represents the valve positions of 0...10%.

Figure 3-8: Histograms
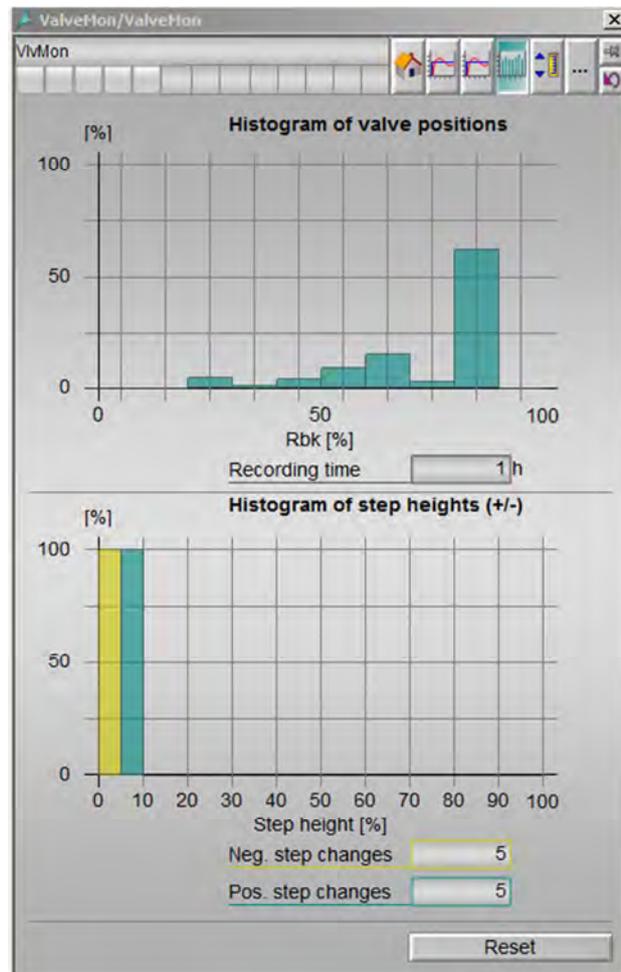
The total time **T_HisPos** is counted using the sampling time and is displayed as recording time in [h]. If the input variable **RstHisOp** =1 (in faceplate, view „Histogram", or in CFC) is set, all counters and the total time **T_HisPos** are reset to zero and restarted.

3.2 Parameter Input in Faceplate or CFC

Histogram for Valve Position

This histogram visualizes the frequency distribution of the different valve positions over the complete valve movement range.

The single counter values per part section are incremented depending on valve position value. They indicate the operating time of the component inside the part sections in % (His*Pos0*...His*Pos10*).

Evaluation of the histogram:

Valves should be operated mostly in the medium range (10...90 %) of possible valve positions, and not at the edges close to start and end position.

- If there are significant accumulations in the range of very small valve openings, the valve is oversized. In the range of very small valve openings the valve characteristic is not reproducible. Process control is difficult here, and there is the danger of cavitation. In addition, a valve almost completely closed will cause stronger pressure losses because of flow redirection and flow through narrow openings.

- If there are significantly accumulations in the range of very big valve openings, the valve is undersized (too small in dimension). A flow controller which relies on such a valve has hardly space to move upwards with its controlled variable, which slows down positive set point steps. If the valve in the fully open position has a smaller cross-section than the pipe, there are turbulences and pressure losses at the junction point.

Histogram Step Height

This histogram visualizes the frequency distribution of the different step heights over the complete valve movement area.

The single counter values per part section are incremented depending on step height. They indicate the operating time of the component for the partial sections in % (*HisStepHiDn1... HisStepHiDn10 und HisStepHiUp1... HisStepHiUp10*).

4 Evaluation for Plant Asset Management

Different results of the calculations performed by VlvMon are relevant for different target groups working in a process plant, and differ with respect to urgency.

Diagnoses like actual valve blockade or compressed air leakage have to be immediately announced as an alarm to the operator, because in such operating conditions the valve is not available for process control.

Other operating conditions like e.g. deviations of the upper and lower end position or the detecting of a steady state control error after the end of the valve move represent only a smaller impairment of process control or will result in valve damage after some longer time.

Hints to deviations of the actual operating point from the reference characteristic do not inevitably indicate a mechanical damage of the valve.

Following these considerations, it is reasonable to evaluate the information created by VlvMon in a target group oriented way.

The VlvMon function block does not include its own messaging.

Warnings and alarms for the operator can be created using the binary output signals of VlvMon. If possible, these output signals are linked to free binary message input variables of the assigned technological function block (e.g. of the VlvAnL function block or flow controller). Otherwise separate Event or MonD function blocks are inserted in the CFC and linked with these.

Maintenance request messages are created according to section 4.3 by the related AssetMon function block.

4.1 Evaluation with Fault Symptom Trees

Different faults which are shown in black in Figure 4-1 can occur in a control valve. These faults lead to observable symptoms via physical cause-effect relationships which can be detected by VlvMon function block. The fault trees help you to conclude the underlying fault causes from the symptoms observed.

Figure 4-1: Fault tree of flow characteristic and end positions
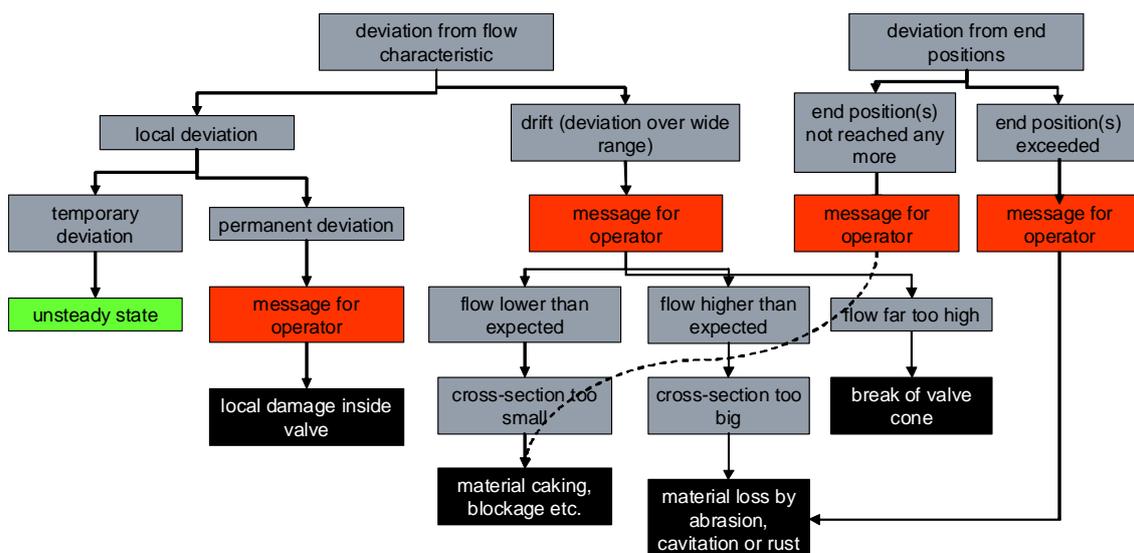
4.1 Evaluation with Fault Symptom Trees

If you recognize a deviation of the reference characteristic in the VlvMon faceplate, you can distinguish whether the deviation extends over a large range of the characteristic or only a small part.

If the deviation is only local and appears only temporarily, it is completely harmless. Since the characteristic only describes the behaviour of the valve in steady state, temporary deviations can appear during transients e.g. after a setpoint step.

Only if a deviation of the actual operating point from the reference characteristic is present for some time, a message is triggered. Permanent deviations which appear only in a certain region of the characteristic line indicate locally restricted damages to valve body or valve seat which have an effect only at certain valve positions.

If the actual characteristic differs from the reference characteristic over a wide range, this is called a characteristic drift, which should be reported to the operator or better to the maintenance personal in any case. Different cases have to be distinguished.

If the flow rate is far too high, i.e. the flow rate lies far above the reference characteristic, it has to be assumed that the valve cone is torn off.
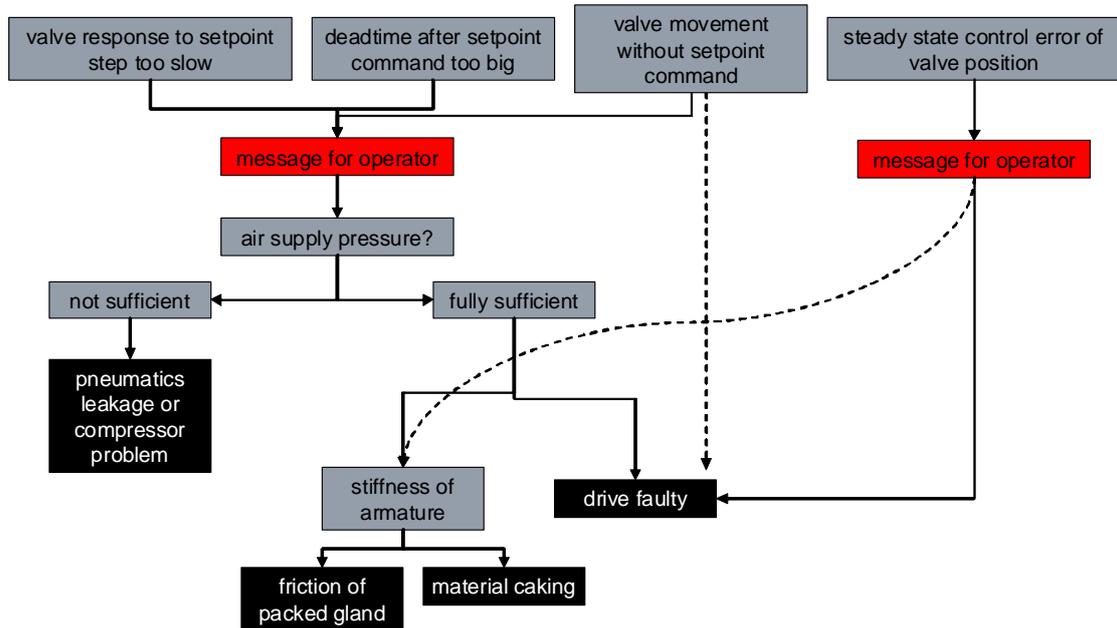
If the actual characteristic of the flow is located a little above the reference characteristic, then the valve cross-section is larger than in good condition of the valve. A material loss inside the valve therefore has to be suspected, caused by abrasion, cavitation or rust.

If the actual characteristic is located below the reference characteristic, the flow rate is lower than expected, i.e. the valve cross-section is smaller than in good condition of the valve. Reasons for this can be material caking at the valve body or the valve seat or a blockage by foreign particles.

Sometimes faults like material caking, foreign particle or abrasion can be detected also without characteristic line monitoring, if the valve is driven to the upper or lower end position. If the upper or lower final position cannot be reached any more, i.e. the valve drives upwards only to 99% or downwards only to 1% for example, material caking or a foreign particle has to be suspected.

If the valve drives upwards over or downwards below the final positions measured in good condition, e.g. reaches feedback positions of less than 0% or larger than 100%, the reason can be material loss.

4.1 Evaluation with Fault Symptom Trees

Figure 4-2: Fault tree of valve movement

If a valve responds too slowly to setpoint steps, i.e. the actual characteristic of the valve response time is located above the reference characteristic, or the dead time which the valve needs to leave its rest-position after a setpoint command is too long, you should check the compressed air supply in any case. Even if the valve moves "by itself", i.e. leaves its position without a setpoint command, just due to the force executed by the medium to the valve body, it makes sense to check the compressed air supply. Otherwise a movement without setpoint command is only possible if the mechanical connection between drive and valve body has loosened.
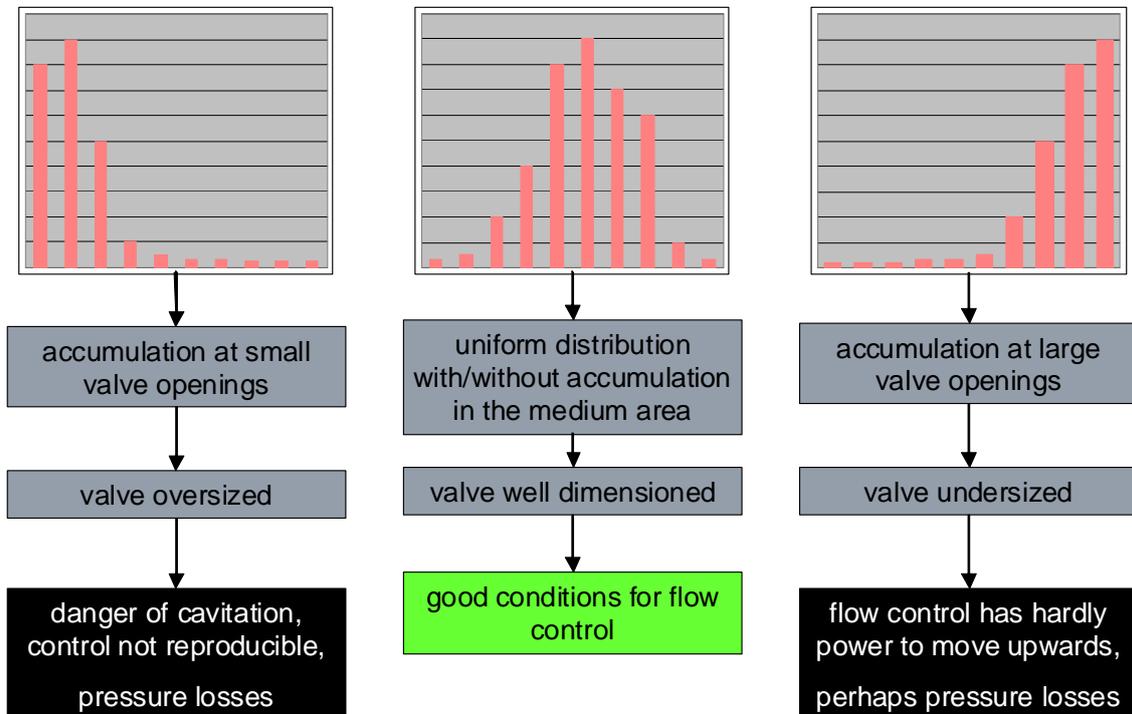
If the compressed air supply pressure is too low, leakages in the pneumatic pipeline system or problems of the compressed air production by the compressor are considered as problem causes.

If however the pneumatics pressure is sufficient, stiffness of the armature or a real defect of the drive is considered as a reason for too slow valve dynamics. Stiffness can be caused both by static friction in the packing gland (seal) of the valve and by material caking at mobile parts.

If a remaining deviation is watched at the valve position, because the feedback position does not reach the setpoint position or there is a continuous oscillation of the position controller, then friction effects or defects of the drive also can be the causes. A wrong parameter setting of the internal position controller also belongs to "defects" of the drive in this context.

4.2   Evaluation of the Histograms

Figure 4-3: Evaluation of the histogram for the valve positions

accumulation at small valve openings	uniform distribution with/without accumulation in the medium area	accumulation at large valve openings
valve oversized	valve well dimensioned	valve undersized
danger of cavitation, control not reproducible, pressure losses	good conditions for flow control	flow control has hardly power to move upwards, perhaps pressure losses

The graphical representation corresponds to the description in section 3.2.4.

4.3   Maintenance Request

A maintenance request announced by a maintenance message is not generated by the VlvMon function block itself, but by the associated AssetMon function block. The AssetMon is a universal proxy function block for mechanic and process assets in the Maintenance Station of SIMATIC PCS 7. The AssetMon block can be replaced by the newer AssetM block from the AP library. The AssetM faceplate is designed according to APL style. In the following only the AssetM is mentioned. It is located in the hierarchy folder of the Maintenance Station and not in the normal plant hierarchy. Its faceplate therefore appears in the Maintenance Station and not in the Operator Station.

The Electronic Device Description (EDD) containing the master data of the control valve is attached to the AssetM block, allowing accessing the valve like an intelligent field device in the context of asset management.

4.3.1   Specification of Control Valve Master Data

In order to generate the EDD for a valve, you need a so called PLT-ID. The PLT-ID is a connection parameter between a PDM object (parameter data EDD) and the faceplate in the maintenance station. The PLT-ID is linked to the PDM object.

The PDM object is generated in the SIMATIC Manager as follows:

1.   Select "View > Process device plant view" in SIMATIC Manager.

2.   Select "Insert > SIMATIC PDM > TAG".

3. Highlight the inserted TAG object and select the context menu command "SIMATIC PDM > Device Selection..".

4. Select "CFC > DATA_OBJECTS > CFC > AssetM" in the tree structure and close the dialog with "OK".

5. In the context menu select "Open Object" and enter all necessary data in the parameter assignment screen form.

6. Select "File > Save". The parameter assignment screen form is closed.

7. Select the TAG object and then Tools > SIMATIC PDM > Create PLT-ID.

You can then assign parameters for the PLT-ID generated automatically at the associated parameter "PLT_ID", view: Details.

| NOTE | The PLT-IDs cannot be changed or deleted individually. |

Now maintenance requests and master data of the control valve are displayed together to maintenance personal.

4.3.2 Linking and Parameterization of AssetM Function Block

After a defined maximal number of strokes resp. shifts of direction the valve needs maintenance in any case. From the output variable *VlvMon.Strokes* resp. *VlvMon.SID* of the VlvMon function block, you can take the overall number of strokes resp. shifts of direction. You have to link these output variables to the analog input variable *PV1* resp. *PV2* of the AssetM function block.

Define the limits for Maintenance Request *PV1_RH* resp. *PV2_RH*, Maintenance Demand *PV1_DH* resp. *PV2_DH* and Maintenance Alarm *PV1_AH* resp. *PV2_AH* such that after the specified number of strokes resp. shifts in direction the desired maintenance request is generated.

The AssetM function block additionally provides seven message input variables (Message1 … Message7), which generate an alarm by setting the variable to 1. For a maintenance request the message input variable Message2 can be used. A maintenance request is e.g. a limit violation of the maximal relative deviation of the actual flow characteristic from the reference flow characteristic. Then the output variable *VlvMon.FlowAct* has to be linked with the input variable **Message2** of the AssetM function block. If further binary outputs of VlvMon function block have to be considered, all outputs have to be linked with an OR-function block and the result with the input variable **Message2**.

4.3 Maintenance Request

Figure 4-4: Linking of AssetM function block for a control valve
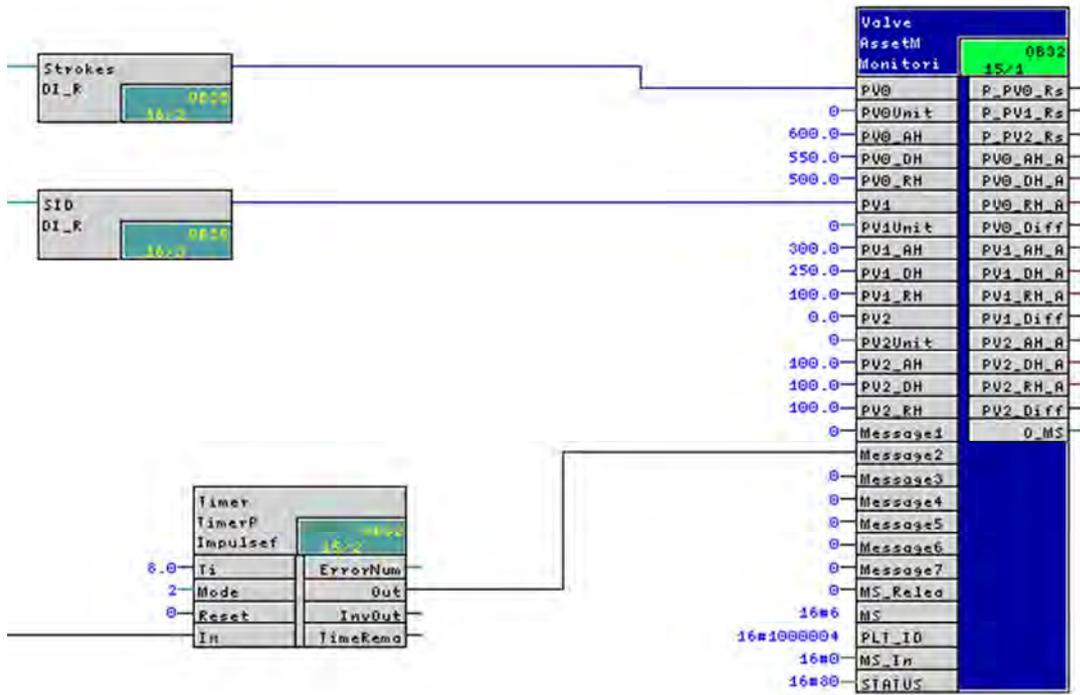
5 Application Example

There is a PCS7 solution template for automation of a pump unit in literature /2/. The pump unit allows generating a controlled flow using a fixed speed pump. Valve monitoring is implemented into this solution template.

Figure 5-1: PCS 7 solution template pump unit
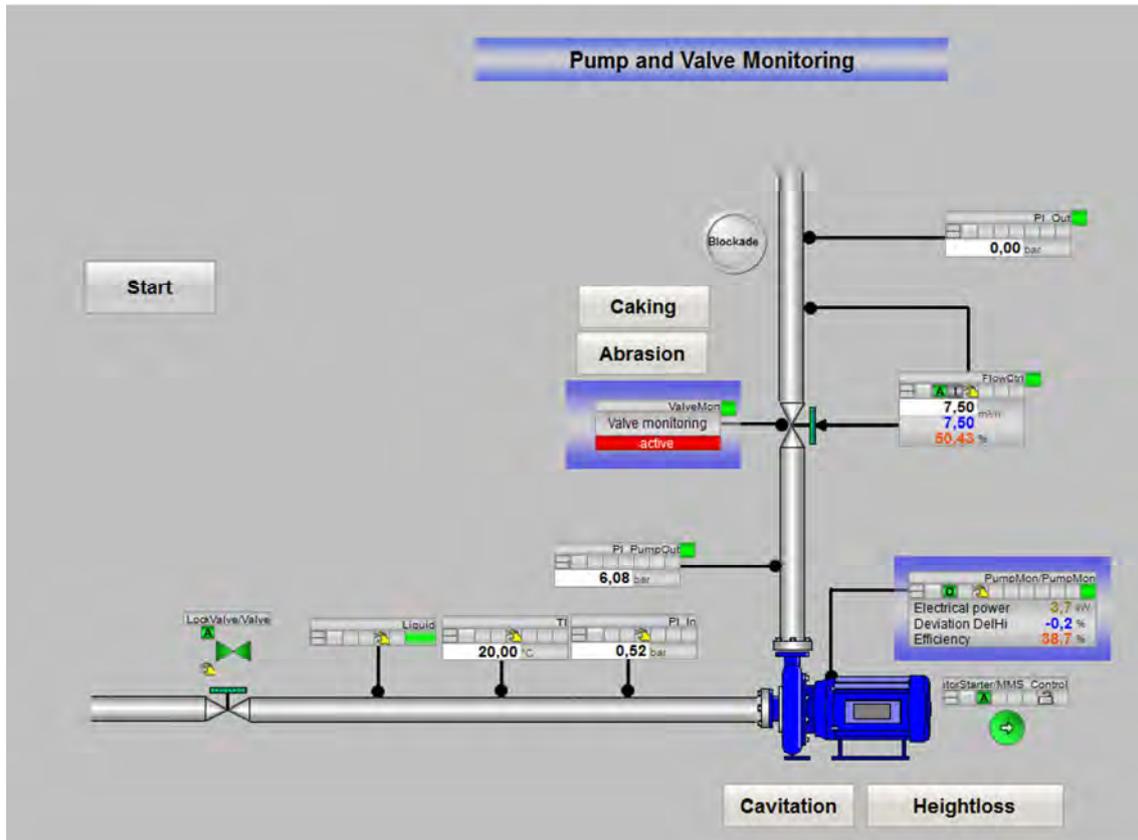
The PumpUnit is extended with the following additional functions and the related measurement tag instances:

- Valve monitoring using the VlvMon function block.
- Pressure sensor installed at valve outlet.
- Detecting steady states for learning of the flow and response time characteristics using the SteadyState function block.
- Optional: Pressure sensor for monitoring the compressed air supply of the valve.

The reference state of a valve is represented in the following figure. There are no drifts away from characteristic lines to be watched. All the operating points are on the reference flow characteristic.

Figure 5-2: Flow characteristic in reference state of valve
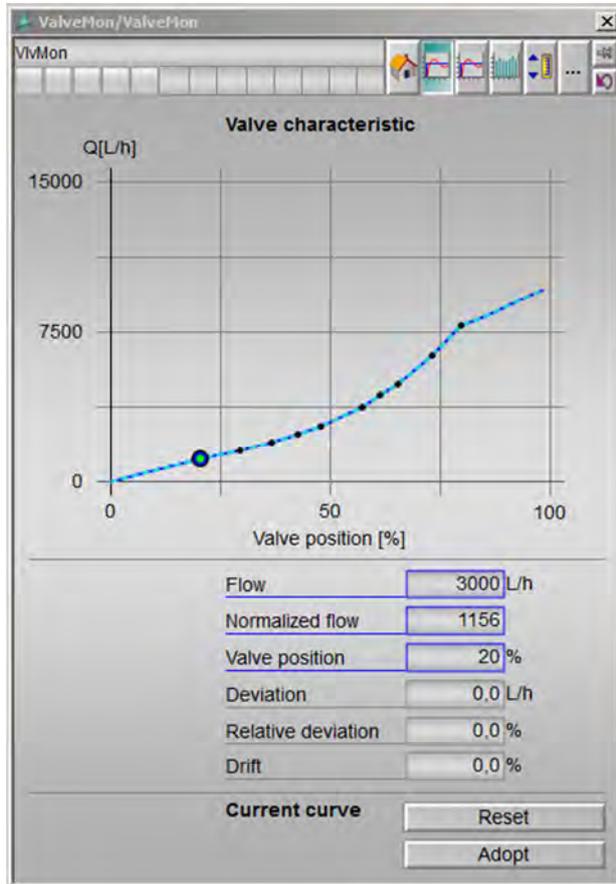
In the following figure a drift can be recognized. The actual characteristic is below the reference characteristic. Reasons for this can be material caking at valve body or blockage.

Figure 5-3: Material caking at valve body
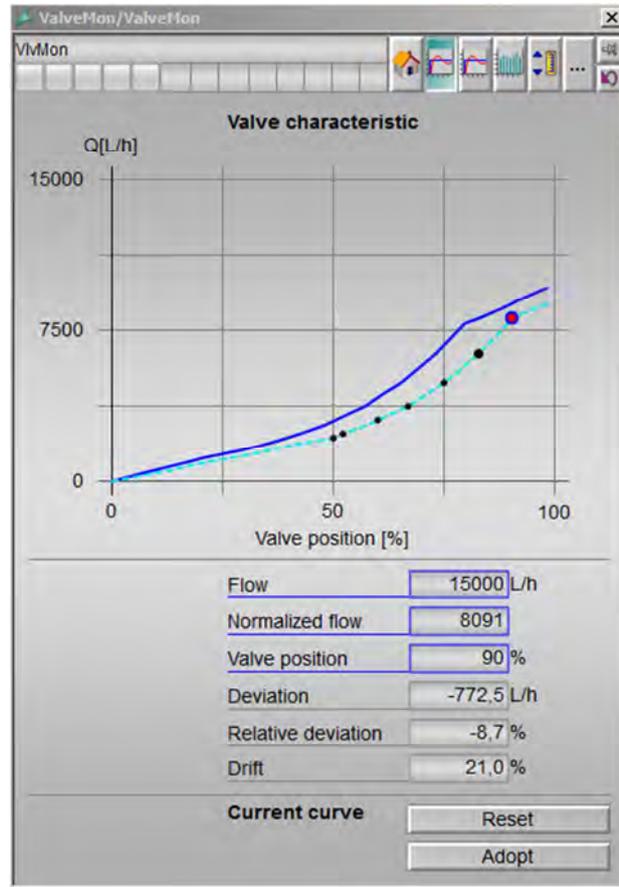
In the next figure a drift can be seen as well. The actual characteristic is above the reference characteristic. It has to be assumed that there is material loss inside the valve, in worst case the valve cone is torn off.

Figure 5-4: Material loss inside the valve
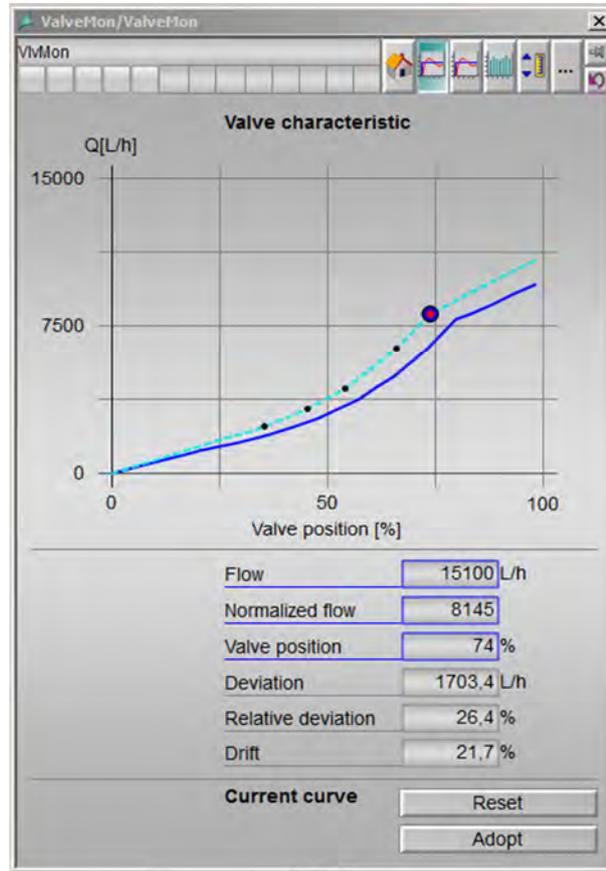
The next figure shows a strong variance of the values learned for the response time characteristic. A dependency of response time on initial valve position was observed in this case. In this case an evaluation of the response time characteristic is pointless.

Figure 5-5: Strong variation of actual response time values
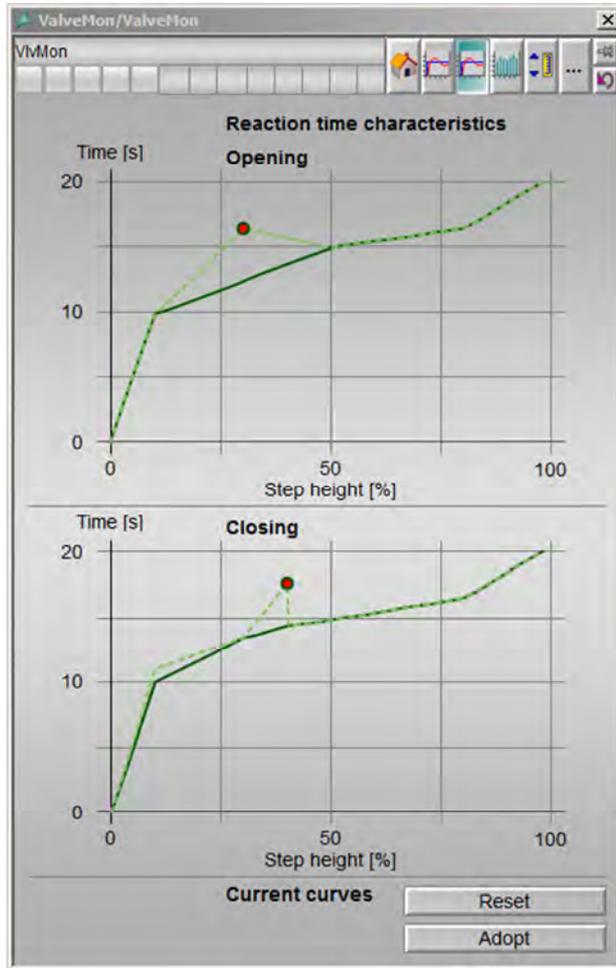
6   Summary

The following table shows the correlation of measurable process variables and detectable problems.

Table 6-1: Diagnostics

	Flow	Pressure difference across valve	Valve position setpoint	Valve position feedback
Hours without movement			x	
Hours without standstill			x	
Number of strokes			x	
Shifts in direction			x	
External movement			x	x
Exceeded upper / lower end position				x
Response time characteristic			x	x
Control error			x	x
Dead time			x	x
Flow characteristic	x	x		x
Histogram valve feedback			x	
Histogram Step height			x	

Legend:

x: Measurement required (mandatory)

7 Related literature

7.1 Further literature

Table 7-1

	Topic	Title
/1/	Realisation of Condition Monitoring Functions with SIMATIC PCS 7	Heinzerling, Till: Realisierung von Condition Monitoring Funktionen mit dem Prozessleitsystem PCS7. Bachelorarbeit des Studienganges Elektrotechnik an der Dualen Hochschule Karlsruhe. Betreuer der Ausbildungsfirma: Jean-Luc Gummersbach, I IA AS PA PM 1; Gutachter der Studienakademie: Dr. Alexan-der Davidenkoff. Sept. 2009.
/2/	Solution-Template Pump-Unit	Müller, P., Pfeiffer, B-M.: Anwenderdokumentation zum PCS 7 Solution-Template Pump-Unit. Siemens I IA&DT ATS 32, Nov. 2007.

7.2 Internet links

Table 7-2

	Topic	Title / Link
\1\	Siemens Industry Online Support	http://support.automation.siemens.com
\2\	Download page of this entry	http://support.automation.siemens.com/WW/view/en/87604493
\3\	Application description: Monitoring of Centrifugal Pumps using the "PumpMon" Function Block in SIMATIC PCS 7	http://support.automation.siemens.com/WW/view/en/42460161
\4\	White Paper - Plant Asset Management of Mechanical Components with SIMATIC PCS 7	http://www.automation.siemens.com/mcms/process-control-systems/en/distributed-control-system-simatic-pcs-7/simatic-pcs-7-system-components/maintenance-station/Documents/WhitepaperMechanicalAssets_EN_August2011.pdf

8 History

Table 8-1

Version	Date	Modifications
V1.0	02/2014	First version