Asset Management of Mechanical Plant Components with SIMATIC PCS 7

SIEMENS

White Paper

Which benefits with respect to operational efficiency, plant availability and maintenance management can be achieved by condition and performance monitoring of mechanical assets in SIMATIC PCS 7?

Up to now plant asset management in process industries is focused on monitoring the state of field devices and automation components in context of maintenance management. Much higher economic benefits can be expected from expanding this concept to the monitoring of mechanical assets like pumps, valves, heat exchangers or turbo compressors.

This whitepaper gives a survey of functions for condition and performance monitoring of mechanical plant assets offered by SIMATIC PCS 7.

Contents

1 Introduction

Facing highly competitive markets and intensive global competition no production plant operating companies can afford production downtimes due to defective plant components. Unexpected plant shutdowns cause double financial losses: the costs for corrective maintenance are by far exceeded by the losses due to production downtime [3.]. Increasing plant availability by hardware redundancy e.g. of pump systems is quite expensive. The so called B-pumps take space in plants or inventories and are activated or exchanged in case of pump failures. However this does not guarantee that the substitute pump will not become damaged and fails as well due to operation outside specification limits e.g. caused by wrong dimensioning.

Early problem detection and predictive maintenance are therefore very important especially in complex, capital-intensive process plants: they contribute to keep plant availability as high as possible and have a positive influence on product quality, plant safety and plant lifetime.

Functions for plant asset management today are available in many distributed control systems. Integrated condition and performance monitoring allows for state-oriented, predictive maintenance.

1.1 Condition Monitoring and Performance Monitoring

Two different approaches with respect to methodology and goals can be distinguished [4.]:

- Condition Monitoring: determination and monitoring of plant and component states. Signal source is component behaviour; goal is to maintain availability and protect components.
- Performance Monitoring: determination of plant and component performance (signal source) and monitoring of process operation. Goal is to maximize production performance; abnormal component behaviour is a disturbance and reduces performance.

Strategies and software tools are similar. Typically the same measurement values are evaluated. Actually condition and performance monitoring are two different views of the same objects. The following example of a human being shows the relation between condition and performance monitoring:

- Condition monitoring for human being, e.g. to take somebody's temperature: an additional information source (e.g. sensor, here: clinical thermometer, otherwise: process model) delivers information on health status. This allows for indirect implications on performance, because a sick person suffering from fever typically does not achieve its optimal performance any more.
- Performance Monitoring for human being, e.g. 100m sprint. The performance (here: running speed) is measured directly during "operation". This allows for indirect implications on health state (condition) if there is reference information on performance in good (healthy) state. If performance falls significantly below optimum, bad condition can be presumed to be the reason (cause) for that.

1.2 SIMATIC PCS 7 Maintenance Station

The Maintenance Station [2.] integrated in SIMATIC PCS 7 distributed process control system provides a complete status overview of all plant components and offers effective diagnostics, service and maintenance of the plant. The SIMATIC PCS 7 Maintenance Station maximizes the economic value of the plant assets and reduces total cost of ownership by helping you reduce unplanned downtime and efficiently use maintenance investment

The Maintenance Station is focused on Plant Asset Management and enables preventive and predictive diagnostics, maintenance, and service of the production plant. In parallel to process control, the Maintenance Station makes available consistent maintenance information and functions for all system components (assets). While the plant operator obtains all relevant information that is necessary for active intervention in a process via the operator system, maintenance and service personnel can check the hardware components of the automation system and process their diagnostic messages and maintenance requests

1.3 Electrical and Mechanical Assets

The Maintenance Station provides the maintenance engineer access to electrical or electronic components in the plant, such as intelligent field devices and I/O modules, field bus, controllers, network components, and plant bus, as well as servers and clients of the operator systems. Intelligent field devices boost comprehensive self-diagnostic functions informing the user if the device is completely operative or if there is a deviation from normal state.

Besides electrical assets, mechanical assets and rotating machines are important components of each process plant: pumps, valves, heat exchangers, compressors etc. In relation to the electrical assets of process measuring and control technology, mechanical assets and plant components are typically more valuable for the plant owner, but they are more vulnerable to wear and tear due to high mechanical stress.

However they are typically not yet integrated into Plant Asset Management systems - in contrast to intelligent field devices, "non-intelligent" mechanical assets without their own electronic and communication interface do not appear by themselves as active objects in a distributed control system (DCS). Only a few very large and valuable mechanical assets (e.g. compressor stations) feature their own dedicated diagnostic systems. The subsequent installation of dedicated sensors for condition monitoring only, like structure-borne sound sensors, vibration sensors or temperature sensors is cost intensive. Now - how to achieve a cost-efficient monitoring of mechanical assets in a DCS?

The answer: ready-made function blocks for certain classes of common mechanical assets provide reliable condition and performance monitoring via intelligent evaluation of sensor signals already available in the DCS. An installation of additional dedicated condition monitoring sensors is therefore not required.

These ready-made function blocks can evaluate several analog and digital values and draw logical conclusions from the combination of several measurement variables. The blocks themselves are designed purely for diagnostic purposes and generate warnings in case of unfavourable operation conditions or violation of wear limits. If desired, an active intervention into plant operation can be realized by wiring of function block output variables, but is not implemented compulsory inside the function blocks. This means that they can be deployed, or even retrofitted, without the risk of affecting the process.

The whitepaper at hand offers a broad survey on monitoring of mechanical assets. More detailed information can be found in the literature cited in the text, e.g. dedicated application notes on special topics like pump monitoring.

1.4 Integration of Assets into Maintenance Station using AssetM

Mechanical assets like pumps, motors, centrifugals or heat exchangers are represented in the SIMATIC PCS 7 Maintenance Station via proxy objects wherein logical rules for generation of maintenance requests are implemented.

The AssetM (APL-Version of AssetMon from Standard Library) is a universal proxy function block for mechanic and process assets in the Maintenance Station of Simatic PCS 7. 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 AssetM function block generates maintenance requests (messages) for maintenance personal, no alarms or warnings for the plant operator.

The Electronic Device Description (EDD) containing the master data of the plant component is attached to the AssetM function block, allowing to access the mechanical asset like an intelligent field device in the context of asset management.

2 Monitoring of Centrifugal Pumps by PumpMon

Pumps are one of the most common rotating machines in process plants. The PCS 7 Add-on product PumpMon [7.] offers a cost-effective solution for monitoring and diagnosis of centrifugal pumps. It is based on an intelligent combination and logical interpretation of measured process values which are (mostly) already available in the DCS, in contrast to high-end condition monitoring systems based on dedicated additional sensors, e.g. vibration sensors or structure-borne sound sensors.

2.1 Area of Application

The function block PumpMon can be used for electrically driven centrifugal pumps with both constant and variable speed.

Typical application examples:

- Pumps that fail more frequently than the average,
- Pumps that are in danger of cavitation, e.g. in water/wastewater sector,
- Pumps where chemical fouling occurs,
- Pumps that are operated in another way than initially planned,
- Pumps that show unaccountable variations in power consumption,
- Applications where the designated behaviour and performance of pumps is to be proven.

2.2 Functional Range

2.2.1 Calculation of Performance Indicators

- Delivery height (pump head),
- Mechanic and hydraulic power,
- Hydraulic efficiency,
- Net Positive Suction Head (NPSH-value),
- „Load distribution“: statistic distribution of flow values.

2.2.2 Characteristic Lines

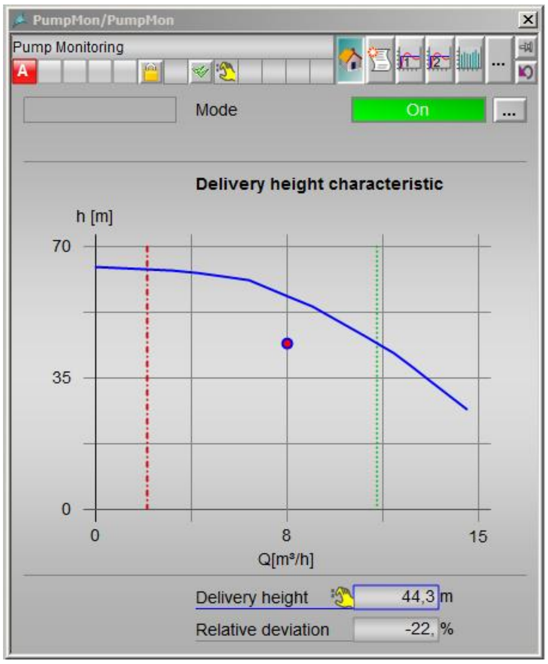

Figure 2-1: PumpMon faceplate, delivery height losses e.g. due to gas conveyance

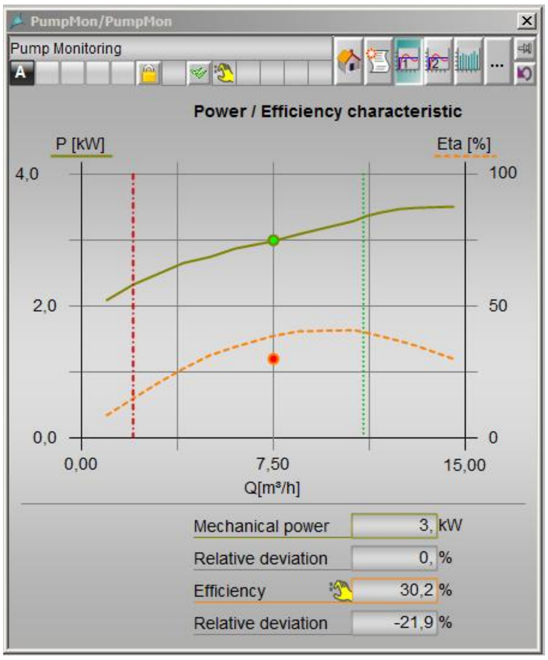

Figure 2-2: Power and efficiency characteristic. Electric power is still a the olive green characteristic line, but hydraulic power is less than expected, i.e. the actual efficiency (in transformation from mechanic shaft power to hydraulic delivery power) is below the respective orange line.

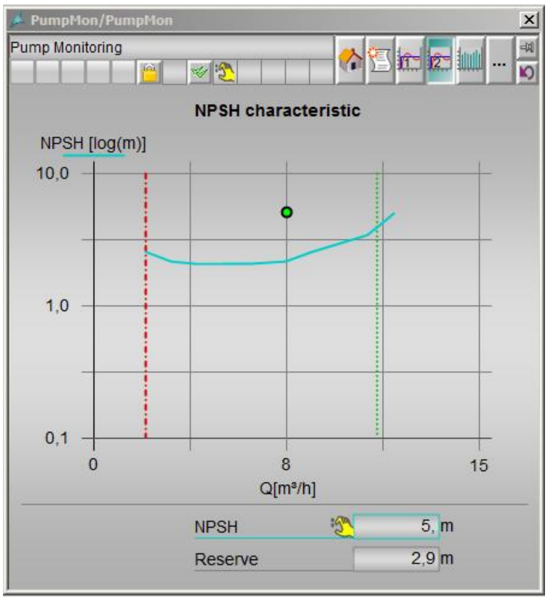

Figure 2-3: Npsh-characteristic during intended operation of the pump

- Delivery height characteristic: display of expected delivery height as a function of flow (in case of speed-controlled pumps converted via the current speed), with minimum and rated flow, „live" actual operating point and relative/absolute deviation of operating point from characteristic line.
- Power characteristic: display of required (mechanical) pump power as a function of flow, with „live" operating point und relative deviation; in addition display of the expected hydraulic pump efficiency as a function of flow with calculated actual efficiency.
- NPSH characteristic: logarithmic display of the NPSHr value required for cavitation-free operation as a function of flow, with actual NPSHa value.
- Histograms: statistical evaluation of pump operating states with respect to flow (pump load) and cavitation reserve.

2.2.3 Alarming

The function block offers the following diagnostic functions for warning operators in case of unfavourable operating states:

- Limit violations of power values,
- Flow lower than minimal flow - extreme turndown, danger of overheating,
- Flow higher than nominal flow - overload,
- Deviation of operating point from delivery height characteristic, i.e. loss of delivery height - indicates gas conveyance, cavitation or blockage,
- Deviation of operating point from power characteristic,
- Deviation of operating point from efficiency characteristic,
- NPSH actual value approaching the NPSH required characteristic - early warning with respect to cavitation.

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

Diagnoses like actual blockage or dry run have to be immediately announced as an alarm to the operator, because these operating conditions will destroy the pump in a short time. An automatic emergency stop of the pump is normally not initiated by PumpMon, but rather by binary interlock logics, e.g. in case of closed valves. In principle, the interlocks can be augmented by evaluation of binary output variables of PumpMon.

Other operating conditions like e.g. cavitation will result in pump damage after some time - however it is advisable to react promptly anyway. In this case diagnosis information has to be announced to the plant operator and to maintenance personal.

Hints like "Pump efficiency is more than 10% below characteristic line" do not call for immediate action, but are helpful to find optimization potential or can be used for predictive maintenance planning.

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

A maintenance request announced by a maintenance message is not generated by the PumpMon function block itself, but by the associated AssetM function block [6.], c.f. section 1.4.

2.3 Sensors

Relevant process sensors for monitoring of centrifugal pumps:

- Effective electrical power intake of motor
- Flow rate of pumped medium
- Pump intake pressure and pump delivery pressure.

For cavitation monitoring additionally:

- Temperature of pumped medium.

For variable speed pumps additionally:

- Pump speed.

These signals have to be provided by signal links or specified in case of constant values (e.g. air pressure, often also intake pressure or temperature of pumped medium). If the frequency converter delivers the mechanical (shaft) power of the motor, this value is also linked to PumpMon.

2.4 Benefit

The diagnostic logic of PumpMon can detect the following unfavourable operating states:

- Blockage
- Dry run
- Delivery height losses e.g. due to gas conveyance
- Wear of crack
- Overload

Overheating, wear and pump damage caused by such operating states can be avoided by warning the plant operator in time. Monitoring of intake pressure and boiling point of pumped medium provides an early warning with respect to danger of cavitation, even before cavitation has reached a strength that is acoustically audible and already causes a lot of wear and tear.

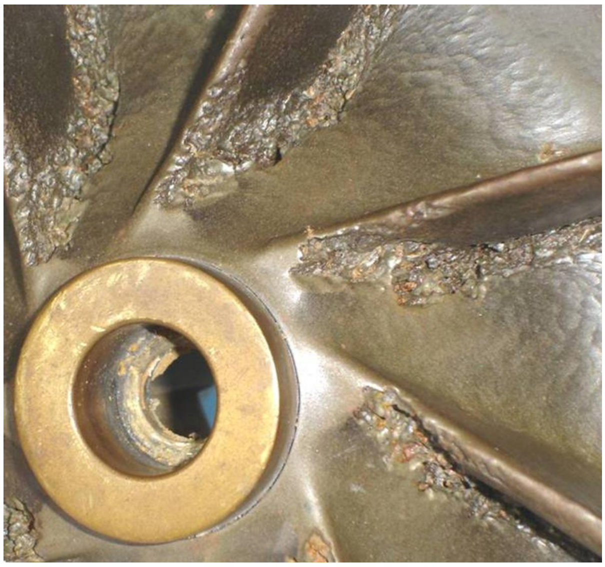

Figure 2-4: Centrifugal pump rotor damaged by cavitation.

Cavitation is the formation and collapse of vapor bubbles of a flowing liquid. During the operation of centrifugal pumps, such vapor bubbles can appear due to (locally) excessive flow velocities: higher velocity causes lower pressure in the fluid. If the pressure of the liquid falls below its vapor pressure, vapor bubbles will emerge. If the pressure rises again in flow direction, the bubbles collapse: the gas inside the bubble suddenly condenses. During this implosion, so called „jet-impacts“ will occur, causing pressure and temperature shock waves, that usually are much higher than tolerable by the materials of pump rotor or pump housing. The surface of pump rotor or pump housing are damaged permanently and finally destroyed. Even a small amount of cavitation reduces the efficiency (the delivery height) of the pump. Full cavitation can even cause the pump delivery to crash completely.

Moreover, PumpMon is helpful for optimization of pump dimensioning by providing statistic evaluation of operation data (load distribution histogram) and supports the discovery of energy saving potentials.

3 Monitoring of Control Valves by ValveMon

Valves just like pumps are one of the most common actuators in process plants. The condition of the valves has a significant influence on the availability and safety of the complete plant. Valves are affected by different signs of wear and tear, such as wear of valve cone and/or valve seat (abrasion, cavitation, corrosion) or fouling (material caking, build-up).

The PCS 7 function block ValveMon 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 ValveMon 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.

3.1 Area of Application

The ValveMon 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 still-stand, etc.) is performed if the valve can not read back the actual valve position (valve position feedback). Control valves with position feed-back permit detecting 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.).

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 characteristics and response time.

3.2 Functional Range

3.2.1 Characteristic Lines

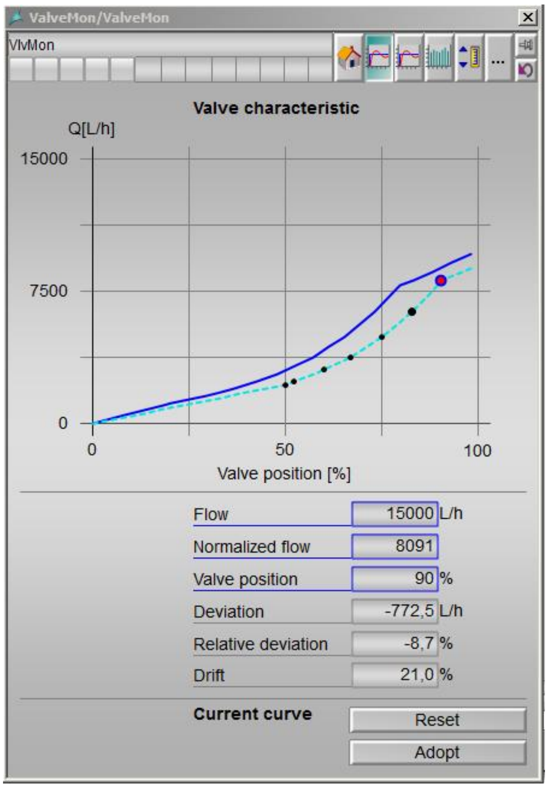

Figure 3-1: ValveMon faceplate, flow characteristic in case of material caking at valve body

- Flow characteristic as a function of valve position, where flow is converted to norm difference pressure. The reference characteristic is specified with constant values, while the actual characteristic is learned from measured data during plant operation, and is adapted automatically (permanently).
- Response time characteristic: display of actual valve response time and reference response time as a function of step height for positive setpoint steps.
- Histograms: statistical evaluation of valve operating states with respect to valve positions.

3.2.2 Diagnostic Functions

The function block offers the following diagnostic functions for warning operators in case of unfavourable operating states or reaching of wear limits:

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- 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.

The function block detects faulty valve movements by the following diagnostic methods. The setpoint provided by the positioner is compared to the real position feedback of the valve.

- 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 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) → caking, stiffness.

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:

- 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.
- Monitoring of air pressure → leakage in compressed air supply.

3.3 Sensors

Required sensor signals for control valves with position feedback:

- flow rate of medium
- valve intake and outlet pressure
- valve position setpoint and position feedback (actual position)

3.4 Benefit

ValveMon provides condition monitoring of control valves based on several process values. Valve malfunctions and developing future valve failures can be detected early by this approach. This allows for an improved maintenance planning and contributes to increase the availability of the overall plant.

The function block ValveMon is applied to

- provide warnings against potential valve damage due to unfavourable operating conditions or reaching wear limits: permanent operation without valve standstill, permanent standstill, violation of maximal number of shifts in directions, violation of operating hours limit.
- provide early detection of developing valve degradation: material caking or deposits, abrasion, wear.
- optimize valve dimensioning in the long term by means of statistical analysis of operating data.

4 Monitoring of Heat Exchangers by HeatXchMon

Heat exchangers are technical components, wherein warmer material flows give away some part of their thermal energy that is taken over by colder material flows. A product medium is to be heated or cooled using a service medium (e.g. hot steam, cooling water). Heat exchangers are consuming significant amounts of energy and need frequent maintenance or cleaning. Heat exchanger performance can be reduced significantly by fouling. Fouling is a general term for all sorts of contaminations in heat exchangers, e.g. sedimentation, corrosion, reaction fouling, bio fouling.

The PCS 7 function block HeatXchMon offers a cost effective solution for monitoring and analysis of heat exchangers. Monitoring is based on intelligent evaluation of measured values and comparison with characteristic surfaces of the heat exchanger. These characteristic surfaces are calculated beforehand via simulations of clean and dirty state of the heat exchanger, using technical data of the heat exchanger. Simulations are performed as part of a service package by Siemens I IA AS PA EC, Frankfurt.

4.1 Area of Application

The preferred application area of HeatXchMon is fluid-fluid tube bundle heat ex-changers. Plate heat exchangers can be monitored if there is a sufficiently precise simulation program for the given type of heat exchanger. Heat exchangers involving a change of aggregate state (reboilers, condensers) can only be monitored by application specific versions of the HeatXchMon function block.

Typical application examples:

- Heat exchangers that tend to corrosion or sedimentation.
- Heat exchangers that are contaminated by micro organisms (bio fouling).
- Heat exchangers where fouling is caused by chemical reactions or reaction products (reaction fouling).
- Heat exchangers with bad or heavily fluctuating efficiency.

4.2 Functional Range

4.2.1 Calculation of Performance Indicators

- Calculation of heat flow $\dot{Q}$ for actual ("act"), clean ("clean") and maximal contaminated ("dirty") state from characteristic surfaces. "Maximal contaminated" refers to a heat exchanger state that requires cleaning immediately.
- Calculation of key performance indicator *HeatPerf* for heat transfer as an indicator of fouling:

$$HeatPerf = \frac{\dot{Q}_{act} - \dot{Q}_{dirty}}{\dot{Q}_{clean} - \dot{Q}_{dirty}} \cdot 100\%$$

  This performance indicator is calculated from the heat flows mentioned above, and can be interpreted as wear out reserve. It is defined such that it will show the value 100% in clean reference state and 0% in maximal contaminated state
- Calculation of energy losses per day, with reference to heat flow in clean state → waste of energy.
- Monitoring of financial losses per day, caused by energy losses → waste of money.

4.2.2 Characteristic Surfaces

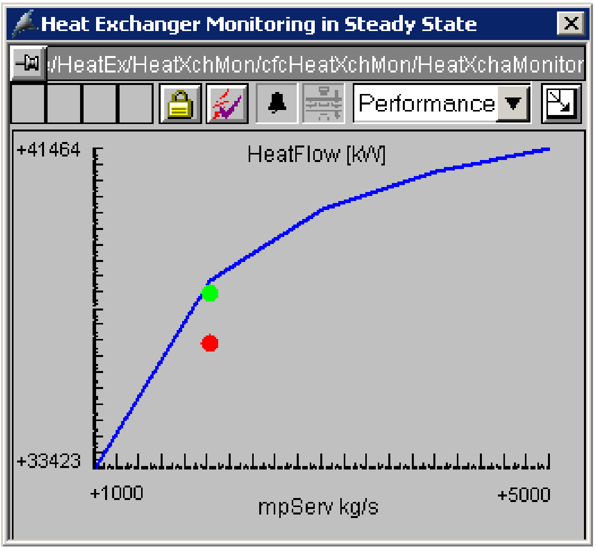

Figure 4-1: HeatXchMon faceplate in nearly clean state, i.e. the actual heat flow (green dot) is close the reference characteristic (blue)

- Display of reference heat flow (heat flow in clean reference state) depending on mass flow of service medium, displayed as two dimensional cut through the five-dimensional characteristic surface. Display of actual heat flow at operating point and in maximal contaminated state.

Figure 4-2: Fouling of tube bundle heat exchanger

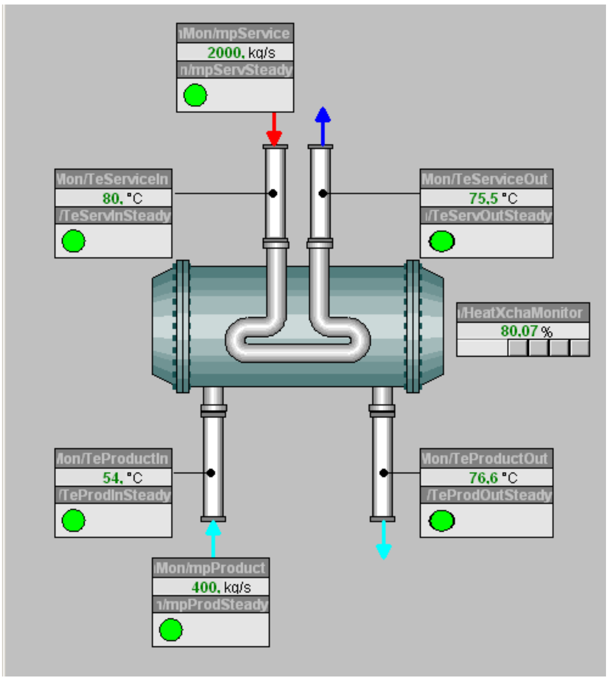

Figure 4-3: Example of heat exchanger monitoring in Simatic PCS 7

4.3 Sensors

For heat exchanger monitoring, the following process values are required, either as measured variables or as constant parameters:

- Service medium flow
- Service medium inlet and outlet temperature
- Product medium flow
- Product medium inlet and outlet temperature

All measured values are low-pass filtered and monitored with respect to steady state conditions by SteadyState function blocks, because the characteristic surface of HeatXchMon are only valid in state states.

4.4 Benefit

HeatXchMon allows condition-based predictive maintenance of heat exchangers depending on degree of fouling. Both wear out reserve and thermodynamic efficiency, i.e. energy losses and financial losses due to reduced heat transfer performance can be considered for scheduling of maintenance actions.

5 Monitoring of Pressure Drop at Plant Components by PressDropMon

In many mechanical assets process plants there is the danger that deposits, material caking or fouling are generated during plant operation which increase the flow resistance of plant components and consequently the pressure drop. This can cause increased energy consumption or reduced throughput, but also disturbances of plant operation or even plant shutdown.

5.1 Area of Application

The PCS 7 functions block PressDropMon [11.] detects such adverse effects and provides

- monitoring of pressure drop at any plant component, and
- early detection of developing blockages.

The block can be used for any flow net components with flow dependent pressure drop. Typical examples:

- Filters
- Precipitators
- Heat exchangers
- Long tubes, pipelines etc.

5.2 Functional Range

5.2.1 Characteristic Lines

- Graphical visualization of pressure drop depending on flow and (if relevant) on viscosity (alternatively temperature) as a reference pressure drop characteristic curve.
- Visualization of actual operation point.
- Calculation of absolute and relative deviation of operation point from the reference characteristic: *DevPres* und *RelDev*.

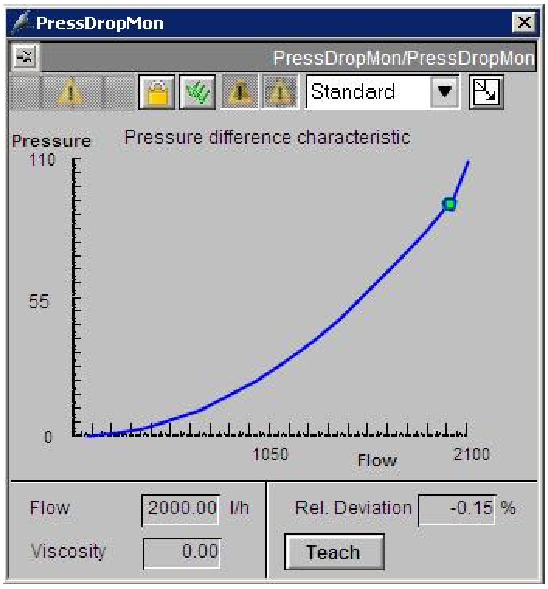

Figure 5-1: Pressure drop characteristic in PressDropMon faceplate, green: actual operating point

5.2.2 Calculation of Performance Indicators

In order to calculate wear out reserve *WearReserve*, the user has to specify a "critical" relative deviation *CriticDev* from the reference characteristic line marking the component state that requires maintenance action immediately, because functional capability of the plant component is in danger.

The wear out reserve is calculated based on the deviations from the reference characteristic as follows:

WearReserve = 1 – (RelDev / CriticDev).

5.2.3 Teach-Function

The teach function provides point wise teaching of the reference characteristic by clicking the teach button. The actual operating point then becomes an interpolation point of the reference characteristic. This way a characteristic surface of pressure drop depending on flow and viscosity can be generated step by step.

Characteristic lines can be specified for up to five different viscosity ranges, i.e. actually the behaviour is defined by a family of characteristic lines where viscosity is the parameter.

5.3 Sensors

Application of PressDropMon requires measurements of flow through the plant component, inlet and outlet pressure. If medium viscosity is varying significantly during plant operation, a measurement representative for viscosity has to be provided, typically the temperature.

5.4 Benefit

The actual operating point is compared to the pressure drop reference characteristic to detect material caking or danger of congestion/blockage inside the plant component. If the deviation of the operating point from the reference curve stays within the parameterized tolerances the operating point is displayed in green. Otherwise a large deviation is visualized by switching the point colour to red.

Deviations from the reference characteristic can be explained by variations of the flow resistance or the cross section available for flow. Mechanical damages or caking inside the monitored component lead to a variation of the cross section of the pipe opening. This results in a modified flow value at constant pressure difference or modified pressure drop at constant flow (depending on whether the pressure or the flow is kept constant by a controller). If the operating point is above the reference characteristic, i.e. if the pressure drop is too high, there is possibly fouling, caking of material or beginning congestion or possibly leakage inside the component. (Remark: leakages between the flow sensor and the component distort the flow measurement and therefore the whole monitoring approach.) If the operation point is below the reference characteristic, perhaps an abrasion or a loss of filtering material is the reason, or a measurement error with respect to one of the three process variables.

Warnings and alarms for the operator can be created using the binary output signals of PressDropMon using e.g. the function block DIG_MON.

A maintenance request announced by generation of a maintenance alarm is not created by the PressDropMon block, but by an associated AssetM block.

6 Monitoring of Compressors by CompMon

The PCS 7 function block CompMon [10.] offers a cost-effective solution for monitoring and diagnosis of turbo compressors. Condition and performance monitoring are based on the intelligent combination and logical interpretation of measured process values which are (mostly) already available in the DCS, in contrast to high-end vibration monitoring systems based on dedicated additional sensors.

6.1 Area of Application

Only continuously operated, rotating flow machines, i.e. turbo compressors are examined. These are frequently used for the conveying or compression of process gasses in process plants. Piston compressors or screw compressors are usually applied for compressed air production for pneumatic valve drives etc. (http://en.wikipedia.org/wiki/Compressed_air). These compressors belong to the class of displacement compressors and displacement compressors are generally not considered for the application of CompMon.

A comprehensive monitoring of compressors with high diagnosis depth can only be developed by the manufacturer of the compressor itself. This is offered for example by Siemens Sector Energy as a "Compressor Awareness system" (CAS) in the context of a service business for the compressors which are designed and sold by Siemens. These compressors are costly individual machines which are designed for special requirements and fabricated in make-to-order production.

A simple performance monitoring based on characteristic curves however is feasible, in the context of PCS 7 asset management and attractive for many customers. Smaller compressors (100kW-2MW) in the industry sectors Chemistry and Oil&Gas are in focus, not the big compressors which anyway bring along a dedicated condition monitoring system.

Instabilities in compressor operation ("surge") have to be avoided absolutely, since pressure shocks appearing can lead to damage or even destruction of the compressor.

Surge (pumping) appears when the compressor does not produce enough pressure to overcome the outflow sided flow resistance. This means that the compressor produces a lower pressure than there is at the compressor outflow. This can lead to a temporary reverse flow into the compressor.

A properly working anti-surge control and a safety instrumented system for surge protection are pre-requisites for the application of CompMon.

Typical application examples:

- Compressors that tend to instabilities in compressor operation (surge).
- Compressors where fouling is caused by chemical reactions or reaction products (reaction fouling).
- Compressors with bad or heavily fluctuating efficiency.

6.2 Functional Range

6.2.1 Calculation of Performance Indicators

The function block CompMon calculates the following aerodynamic performance indicators:

- Specific isentropic and polytropic delivery work,
- Isentropic and polytropic efficiency.

6.2.2 Characteristic Surfaces ("Compressor Maps")

The CompMon faceplate shows four different characteristic surfaces ("compressor maps"). The first and the second are approximately independent of suction side pressure and temperature, and are edited with parameters taken from technical documentation supplied by the compressor manufacturer.

- Polytropic head (delivery work) as a function of volume flow, with the surge line in red colour. The characteristics start on the left side at the surge line. The right end of each characteristic represents the so-called "suction limit".
- Polytropic efficiency as a function of volume flow.

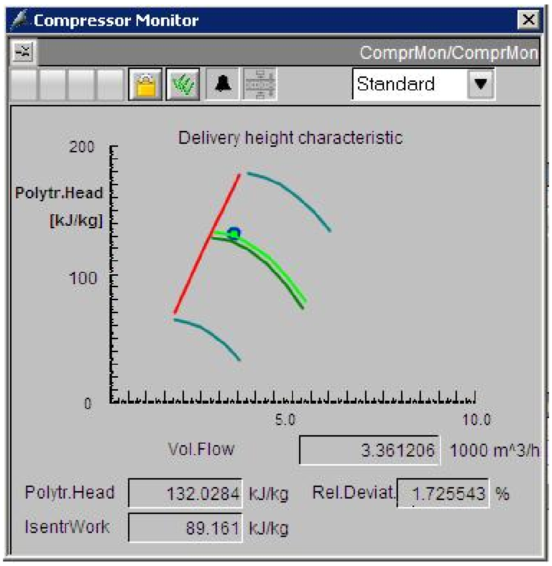

Figure 6-1: Compressor map for polytropic head (delivery height) in CompMon faceplate

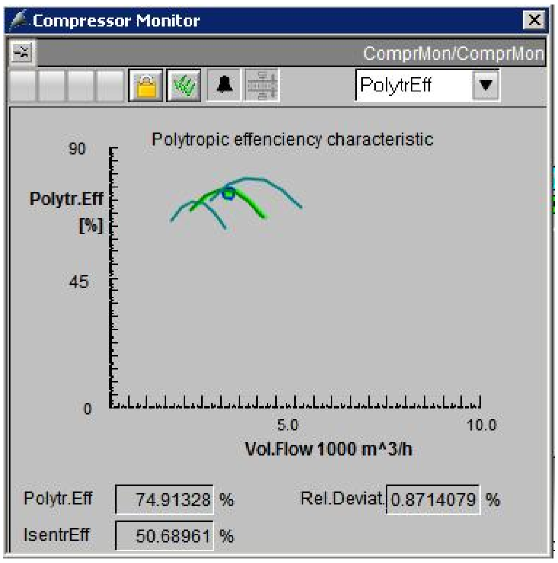

Figure 6-2: Characteristic lines for polytropic efficiency

The other two compressor maps are derived from the first two by thermodynamic calculations inside the function block, such that no separate source data have to be specified for them.

- Discharge (outlet) pressure as a function of mass flow.
- Hydraulic power as a function of mass flow. In relation to this characteristic, the actual mechanic shaft power is displayed. The maximal rated drive power is shown as a horizontal line.

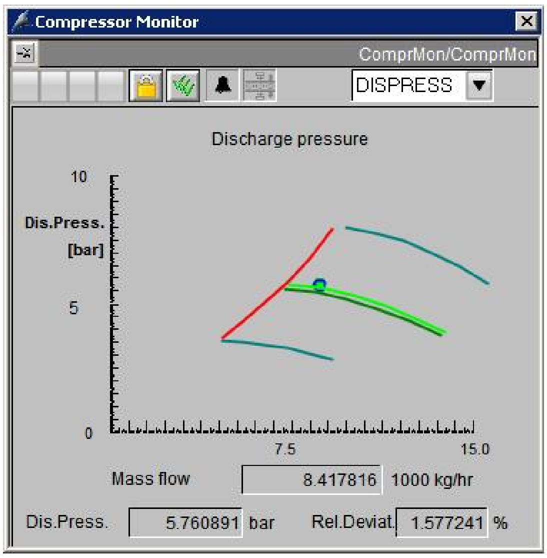

Figure 6-3: Compressor map for discharge pressure

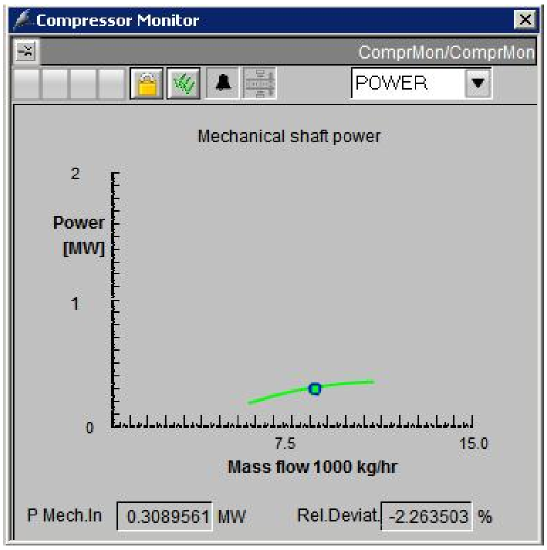

Figure 6-4: Characteristic line of hydraulic power and mechanic shaft power

All characteristic lines of a family depend on a parameter, in this case the manipulated variable of the pressure controller, namely rotation speed or IGV (Inlet Guide Vane).

The delivery height of flow compressors depends on the spin increase of the gas in the compressor. The delivery height can be adjusted by suction sided (inlet) guide vanes such that the guide vanes apply a spin to the intake gas flow in the same or contrary to the rotation direction of the rotor and the circumferential speed of the intake gas flow increases (concurrent spin, reduces delivery height) or degrades with that (countercurrent spin, increases delivery height).

Three characteristic lines of the family are stored as source data, namely for maximal speed (typically 105%), minimal speed (typically 70%) and nominal speed (100%). The characteristic line for actual speed is calculated from these by interpolation.

6.2.3 Alarming

Messages can be generated by deviations of the actual operating point from one of the four characteristic lines for the reference state. Violations of tolerances trigger generation of messaged by CompMon and are offered as binary output variables for linking to further function blocks.

6.3 Sensors

Relevant process measurements for compressor monitoring:

- Compressor intake pressure
- Compressor outlet pressure
- Compressor intake flow rate
- Compressor intake temperature
- Compressor outlet temperature
- Bypass-valve position (setpoint and position feedback)
- Mechanical shaft power of the compressor drive
- Speed or IGV-position

In multistage compressors each "stage group" is considered separately, which requires a conversion of the volume flow and sufficient instrumentation also in between the stage groups. Instrumentation between stages is typically not available in multistage compressors for compressed air production of processing plants so that the CompMon function block is not suitable for such applications.

6.4 Benefit

The compressor typically belongs to the particularly critical and cost-intensive components of a plant. The protection of the compressor from surge damages by monitoring the actual operating point in the compressor map, the detection of slow fouling or damages developing suddenly or slowly at the vanes can be improved by application of CompMon. This way the operational availability of the complete plant is also increased.

Compressor damages that can be detected by CompMon also include problems caused by caking of dust particles at the rotor or rotor erosion by fluid hammer.

Long term optimization of compressor dimensioning is supported by statistical evaluation of operating data, namely a histogram of operation in different load ranges.

7 Extrapolation of Wear Trends and Estimation of Remaining Service Life by TrendMon

7.1 Area of Application

Using the PCS 7 block TrendMon, the wear reserves calculated by PressDropMon or other XxxMon asset management function blocks can be processed such that the time trend is extrapolated into the future. This way the remaining service life of the monitored component can be estimated. To avoid a plant shutdown, the respective plant component must be cleaned, maintained or exchanged during this remaining service time.

Typical application examples for TrendMon are all plant components which are monitored with respect to wear and for which an estimation of remaining life time (service time) is important for the plant operator:

- Monitoring of flow resistances with PressDropMon function block: The output variable *WearReserve* is calculated from the deviation of actual operating point and reference operating characteristic curve, and can be linked to TrendMon.
- Monitoring of heat exchangers with HeatXchMon function block: The output variable *HeatPerformance* (0...100) describes the performance of heat transfer. It can be divided by 100 and interpreted as wear reserve. Therefore it can be directly connected to the TrendMon block. At *HeatPerformance*=0 the heat exchanger fouling has reached a state where cleaning is mandatory.
- Monitoring of valves with ValveMon function block: The output variables *Strokes* and *SID* describe the number of strokes and the number of shifts in direction. If the valve manufacturer declares a maximum life cycle of “MaxStrokes”, then you can calculate the wear reserve in the following way:
  WearReserve= 1 - Strokes/MaxStrokes
  The deviation of the actual operating point from the expected flow characteristic can be used to calculate a wear reserve in an application specific way if it is known at which deviation cleaning is mandatory.
- Monitoring of centrifugal pumps with PumpMon function block: The output variable *DevDelHi* describes the relative deviation from the delivery height characteristic and provides an indicator of potential wear. According to application specific know-how it can be decided which loss of delivery height requires maintenance action. Wear reserve for the TrendMon block is calculated in CFC using elementary arithmetic function blocks.
- Monitoring of compressors with CompMon function block: According to the type of pumped medium pollution, caking and abrasion can appear which affect hydraulic performance. It can be decided in an application specific way which deviation from hydraulic performance characteristic requires maintenance, and wear reserve for the TrendMon block is calculated accordingly in CFC.

7.2 Functional Range

Graphical visualization of the time trend of the input variable *WearReserve* in the past and linear extrapolation of this trend into the future.

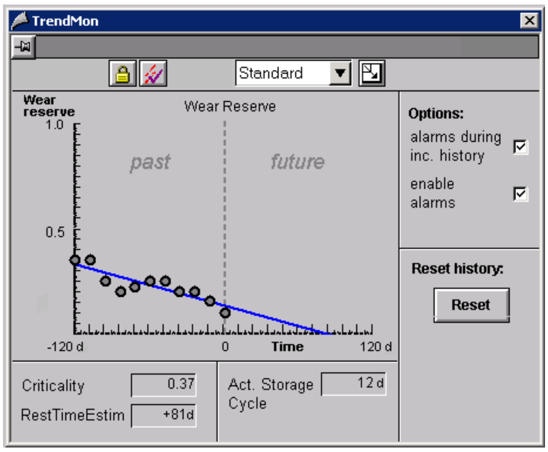

Figure 7-1: Extrapolation of wear reserve from the past to the future in TrendMon faceplate

7.3 Benefit

The estimated value for the remaining service life time is compared to a "minimal requested remaining life time"; the result is a value called “criticality”:

Criticality = RestTimeMin / RestTimeEstim

If the remaining life time becomes smaller than "minimal remaining time" the criticality becomes greater than 1 and the corresponding binary output *RestTimeUnderrun* of TrendMon is set to true. The criticality can be used to generate a maintenance request (maintenance alarm) if this output is connected to an AssetM function block.

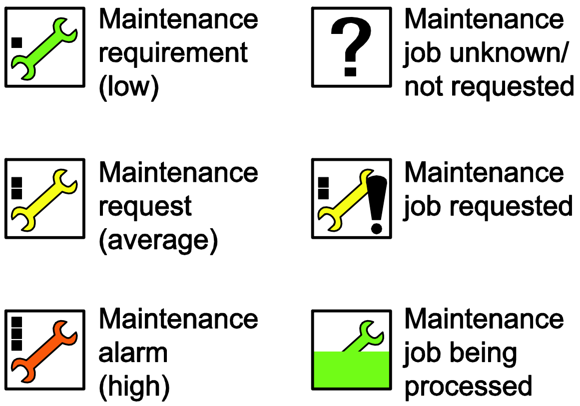

Figure 7-2: Symbols for status of assets in PCS 7 Maintenance Station

For this, the criticality of asset state is linked to an analog value monitoring input of the associated AssetM function block. The maintenance alarm limits are set e.g. to

- 0.7 for maintenance request (green screw wrench),
- 0.9 for maintenance demand (yellow screw wrench),
- 1 for maintenance alarm (red screw wrench).

8 Monitoring of Typical Process Plant Unit Operations

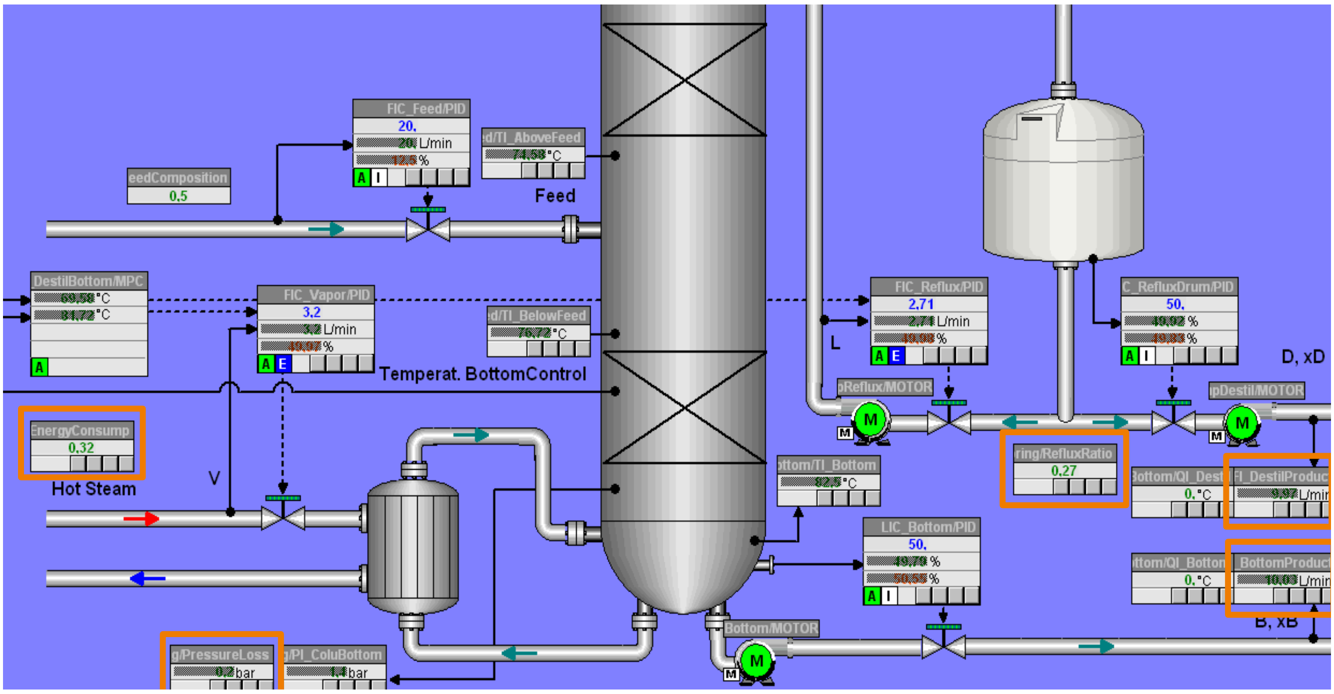

Figure 8-1: Key Performance Indicators (KPI) for monitoring of distillation columns, from left to right: relative energy consumption, pressure loss, reflux ratio, throughput and product quality

Specific unit operations are typically performed in specific types of process plant units (apparatus) like e.g. continuously stirred tank reactors (CSTR) or distillation columns.

Pre-fabricated solution templates for the automation of such plant units allow integrating asset management functions. These include instances of universal asset management functions:

- Monitoring of centrifugal pumps, valve and heat exchangers belonging to the unit by XxxMon function blocks.
- Monitoring of all control loops by ConPerMon function blocks (Control Performance Monitoring, [5.])

Moreover, solution templates allow defining specific functions for calculation of unit-oriented KPIs (Key Performance Indicators), as shown in the following examples.

8.1 Continuously Stirred Tank Reactors

A chemical reactor is applied to generate one or more products from several reactants. Inside of a reactor there can be one or several phases (fluid, solid, gaseous) and one or several reaction kinetics. The following key performance indicators are generally valid for all chemical reactors [4.]:

- Product quality with specifications like purity (e.g. minimal required concentration of one or more product components, maximal allowed concentration of one or more by-products / impurities) or other product properties (e.g. molar mass distribution, viscosity, melt-index, colour, aroma).
- The conversion rate in batch-processing is the amount of converted reactant (limiting reaction stoichiometry) related to the reactant provided at starting time t=0. In continuous processing the conversion rate is the ratio of reactant converted (from inflow to outflow) and reactant inflow.
- Yield is the ratio of generated product (molar amount) and provided reactant (molar

amount) which is limiting reaction stoichiometry.

- Selectivity is the ratio of generated product [mol] to consumed reactant [mol] which is limiting reaction stoichiometry.
- Specific energy consumption: chemical reactions consume energy or generate heat. The specific reaction enthalpy is theoretically known and can be compared via thermal energy balances to the amount of heat generated or consumed by the production.
- Specific catalyst consumption: ratio of catalyst mass flow and product mass flow.
- Space-Time-Yield or reactor capacity: production performance (product mass flow) per reactor volume unit.
- Off-Spec production (mass or mass flow)
- Hold-up time or hold-up time distribution.
- Mixing quality, mixing time, dead volume.

8.2 Rectification- and Distillation-Columns

Rectification (counter flow distillation) is a thermal separation process used on a liquid mixture for separating different substances soluble in each other by means of their different relative evaporation and different boiling points. The low boilers ("tops") are drawn off at the head (top) of the rectification column and the high boilers ("bottoms") are drawn off at the bottom. The performance is generally evaluated using the following key performance indicators:

- Purities of head and bottom product, eventually intermediate side outlet.
- Specific energy consumption (heating vapor) per feed flow or per product outflow.
- Reflux ratio, i.e. ratio of reflux and head product outflow.

Higher reflux ratios can achieve higher product purities of head and/or bottom product. Reflux ratio and specific energy consumption depend on each other, i.e. higher reflux ratio requires higher energy consumption. If those values do not correspond to the nominal or specified values, the column is not operated optimally, or there is a problem with the trays inside the column.

- Pressure loss (pressure drop) of the whole column or parts of it.

If pressure loss is higher than expected, this is an indicator of damages or pollution (corrosion, fouling) of column trays, plates or packing material.

In the PCS 7 solution template for automation of distillation columns ([12.], [13.]) ready-made functions for calculation and monitoring of these key performance indicators are integrated.

Further solution templates for typical unit operations have been developed as prototypes and are prepared for download:

- Continuously stirred tank reactor with cooling jacket,
- Bioethanol fermenter,
- Polymerisation reactor with advanced process control,
- Fluidized bed dryer with advanced process control.

9 Summary

Automation by SIMATIC PCS 7 significantly contributes to minimizing plant operation and maintenance costs.

The enhancement of plant asset management to include mechanical plant components like pumps, control valves, heat exchangers or compressors is a promising approach. Benefits with respect to plant availability, maintenance costs and plant performance can be achieved by condition-based predictive maintenance, extension of maintenance intervals, prevention of unplanned plant-shutdowns and increased energy efficiency.

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www.siemens.com

Siemens AG

Sektor Industry, IA AS SM MP7
Östliche Rheinbrückenstr. 50
D-76181 Karlsruhe