Monitoring of Centrifugal Pumps using the PumpMon Function Block

SIMATIC PCS 7

Application • April 2010

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SIMATIC PCS7 PumpMonitoring

Application

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1 Preface

Objective of the Application

The objective is performance monitoring and diagnostics of centrifugal pumps 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 high-end condition monitoring systems based on dedicated additional sensors, e.g. vibration sensors or structure-borne sound sensors.

Main Contents of this Application Note

The following issues are discussed in this application:

- How to implement and configure the pump monitoring, using the PCS 7 Add-on product.
- How to parameterize and commission the pump monitoring.
- How to evaluate the pump monitoring results in the context of plant asset management.
- Application example based on the PCS 7 solution template "PumpUnit".

Validity

Valid for PCS 7 V6.1 and V7.0. The application example is based on PCS 7 V7.0 SP1.

Reference to Automation and Drives Service & Support

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2 Introduction Pump Monitoring

NOTE

A general overview of pump monitoring in PCS 7 is provided by the White Paper „SIMATIC PCS 7 Monitoring Block PumpMon - Function Block for cost-effective Monitoring and Diagnostics of Centrifugal Pumps "
http://www.automation.siemens.com/w2/efiles/pcs7/pdf/76/Paper_PumpMon_AM_CM_EN.pdf

2.1 Area of Application

Pumps are one of the most common rotating machines in process plants. The PCS 7 Add-on product PumpMon [1.] 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.

The function is applied to

- provide warnings against potential pump damage due to unfavorable operating conditions (blockage, dry run, gas conveyance, cavitation, overload, incorrect direction of rotation);
- provide early detection of developing pump degradation (wear and tear, decreasing pump efficiency);
- optimize pump design over the long term by means of statistical analysis of the operating data and load profiles. This way, potentials for energy savings can be detected.

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

PumpMon can inform operators via alarm and warning messages about any violations of the nominal pump operating range and about deviations from the expected characteristic, and make this data available for further processing via the block outputs. Of course, all the output values can be processed further by means of the usual PCS 7 tools (calculations, trend recording, alarm history, and so on).

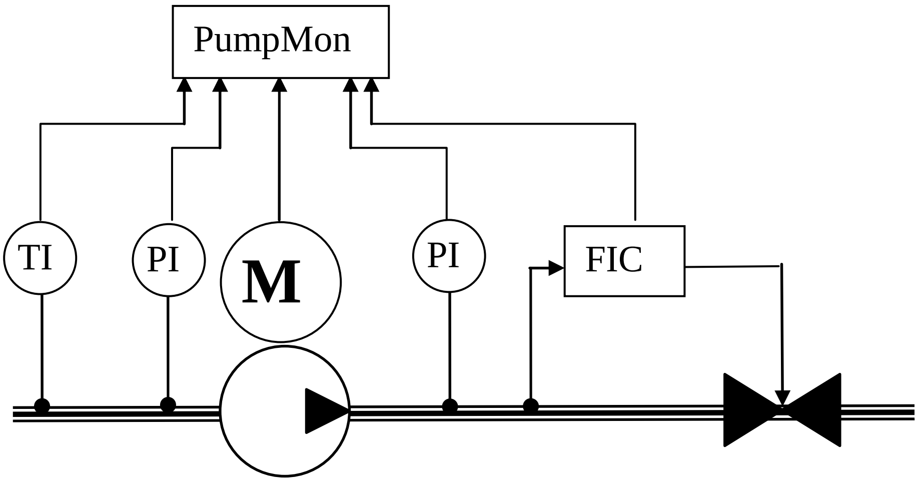

Figure 2-1: P&I-diagram of pump with associated sensors and actors incl. pump monitoring

The block itself is designed purely for diagnostic purposes and, as such, does not intervene directly in the operation of the pump. This means that it can be deployed, or even retrofitted, without the risk of affecting the process. If required, active intervention (e.g. to reduce the speed of the pump in response to imminent cavitation) can be achieved by evaluating the block outputs.

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.

2.2 Functions

The PumpMon function block offers the following functions [1.]:

2.2.1 Analysis and Graphical Representation of Characteristics of Pump Data and Operation States

- Power values: electric power intake of the motor, calculated mechanical power output of the motor, hydraulic power delivered by 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 (calculated from intake pressure and vapor pressure of medium). NPSH stands for „Net Positive Suction Head“.
- Histograms: statistical evaluation of pump operating states with respect to flow (pump load) and cavitation reserve.

2.2.2 Diagnostic Functions

The function block offers the following diagnostic functions for warning operators in case of unfavorable 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.

2.2.3 Teach Function

Point wise teaching of reference pump characteristics via coordinates of interpolation points in good state (reference state) of the pump.

2.3 Typical Application Examples

- Pumps that fail more frequently than the average,
- Pumps that are in danger of cavitation, e.g. in water/wastewater sector [6.],
- 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 behavior and performance of pumps is to be proven.

3 Implementation of Pump Monitoring

3.1 Installation of SIMATIC PCS 7 Add-on Product

The installation of the SIMATIC PCS 7 Add-on Product is performed by the setup program of the delivery CD. The function block can be installed in PCS 7 Version 6.1 or higher.

After installation, there is a library called „PCS 7 PumpMon Lib V10“ available in Simatic Manager. After selection of the function block PumpMon in the blocks folder, the online help can be called via function key F1.

If the PumpMon faceplate is not displayed properly in OS, the PumpMon setup must be installed not only on the ES and OS server, but also on each OS client.

3.2 Configuration

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

3.2.1 Greenfield Engineering of the Complete Automation Around a Pump (Based on Solution Template)

Around pumps, there is a typical combination of actors and sensors, that (together with the pump) provide the equipment module "create defined (controlled) flow of a fluid and monitor it". Therefore it is reasonable to standardize the pump in form of a "pump unit", together with the actors and sensors that belong to this equipment module. The typical control and interlock functions, that are necessary for all pumps in a similar way, and the pump monitoring (using the PumpMon function block) all belong to the automation of the pump unit.

If pump speed is fixed, PI flow control is acting on a control valve next in line. The pump itself is controlled via a direct starter e.g. Simocode.

A lock valve in front of the pump makes sure that no fluid is travelling through the pump if the pump is switched off. Besides flow indication for flow control, there are sensors for pressure at suction side and load side, and for medium temperature. A binary fluid detector observes if there is any fluid at all.

The pump drive is stopped or prevented from starting if

- the inlet (lock) valve is closed, or
- the control valve at the outlet is nearly closed by the flow controller for some time (e.g. longer than 10s in a position with less than 5% opening).

It is recommended to realize two different types of pump units in the library part of a PCS 7 multi project: one pump unit for fixed speed pumps with flow control via control valve, and one for variable speed pumps with flow control via pump speed.

3.2.2 Retrofitting of Pump Monitoring in a Running Plant

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

The function block PumpMon is inserted in a CFC chart in the appropriate folder of the technological hierarchy. Because PumpMon connects sensor signals from different measurement tags, you will typically generate a new chart for it. This chart be located in the hierarchy folder to which the pump belongs, or in a separate hierarchy tree plant diagnosis or "performance station". In a performance station 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 the performance station are plant managers, process and control engineers that are responsible for optimizing plant operation.

3.2.3 CFC Engineering

The function block requires:

- effective electrical power intake of motor → Input variable ***PoElec***
- flow rate of pumped medium → Input variable ***Flow***
- pump intake pressure → Input variable ***P_In***
- pump delivery pressure → Input variable ***P_Out***
- a binary signal indicating if motor is running → Input variable ***Running***

If measured pressure values only determine pressure difference to surroundings:

- air pressure to be added as an offset to measured pressure values → input parameter ***P_Atmos***

For cavitation monitoring additionally:

- temperature of pumped medium → input parameter ***Temp***

For variable speed pumps (input parameter *ConstSpd* = FALSE) additionally:

- pump speed → input variable ***Speed***

If the frequency converter delivers the mechanical (shaft) power of the motor:

- mechanical power → input variable **PoMech**

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). The values are normalized to SI units if necessary, by using the input parameters ***Offs*** and ***Fact*** .

If you are normalizing temperature values, pay attention to the details in the description [2.]!

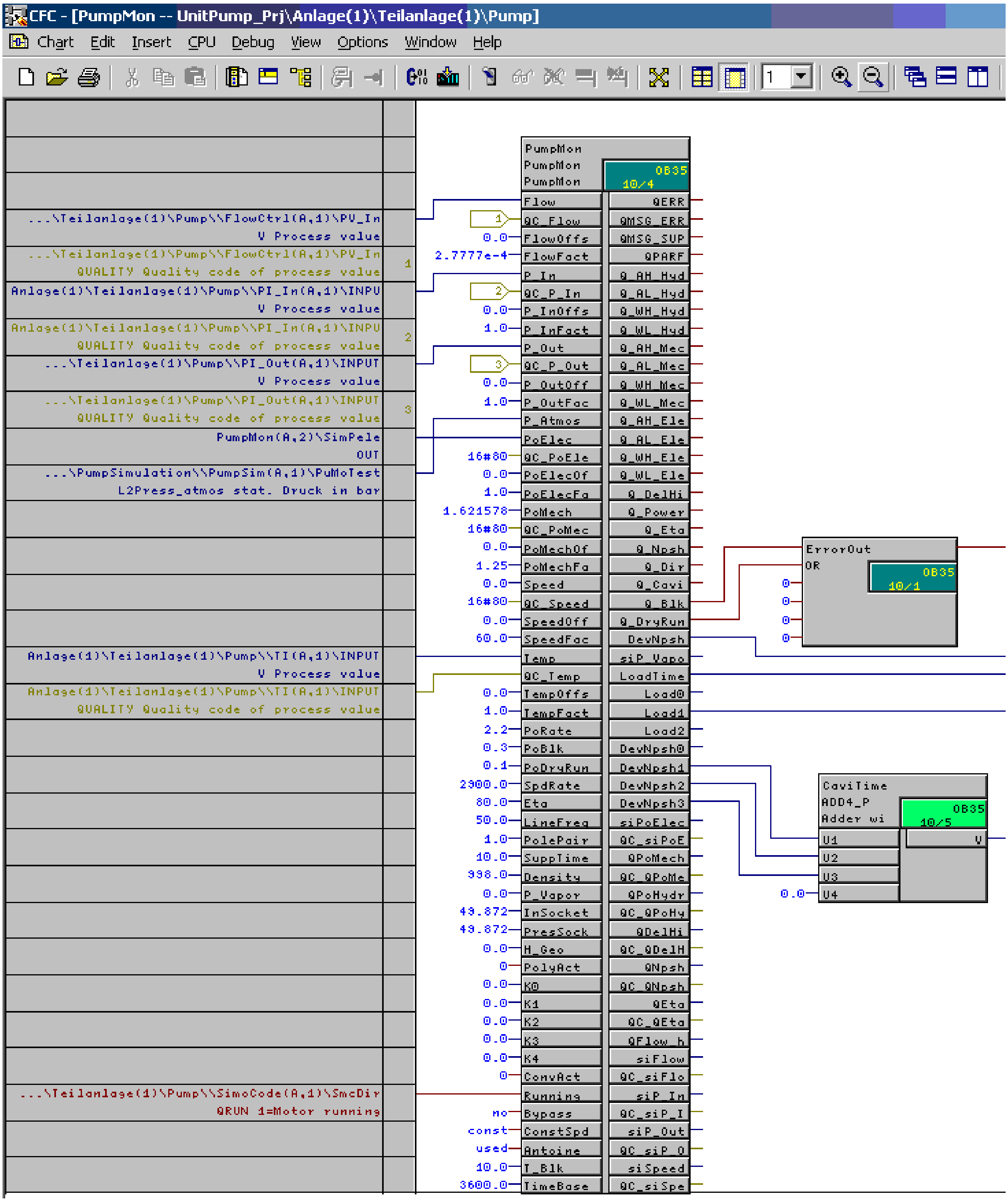

Figure 3-1: Linking of PumpMon function block in CFC

4 Parameter Specification and Commissioning

4.1 Required Data for Motor, Pump and Pumped Medium

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

4.1.1 Data of Electrical Motor

General

- Rated speed

For standard motors:

- Rated power
- Rated efficiency

For non-standard motors, e.g. canned motor pumps:

- Polynomial to calculate the delivered mechanical shaft power as a function of consumed electrical power (must be delivered by supplier of motor/pump)

4.1.2 Data of Pump

- Minimal flow
- Rated flow
- Delivery characteristic = H/F- characteristic
- Power characteristic = P/F- characteristic
- Efficiency characteristic

NOTE The pump efficiency is calculated in the PumpMon function block as a ratio of hydraulic power and mechanic shaft power. Sometimes this efficiency is not identical to the efficiency rated in the pump specification: in the pump specification there is frequently only the efficiency of the rotor, while other power losses (e.g. eddy currents, bearing losses, friction losses) are ignored. Therefore it is to be expected that the pump efficiency calculated by PumpMon is a little bit below the rotor efficiency rated in the pump specification.

For cavitation monitoring additionally:

- NPSHr characteristic
- Diameter of pump intake and pressure socket
- Eventually recommended minimal distance to NPSHr characteristic for long term operation (typically 0,5m)

4.1.3 Data of Pumped Medium

- Density

For cavitation monitoring additionally:

- Antoine coefficients, if medium is different from water 0 – 100ºC, or
- Algorithm for calculation of vapor pressure as a function of temperature if Antoine equation is not applicable.

4.2 Parameter Input in Faceplate or CFC

4.2.1 Parameters of Electrical Motor

Specification of calculation method for mechanical shaft power (CFC only)

1. For standardized motors (***PolyAct*** = FALSE, ***ConvAct*** = FALSE, default setting)
→ Calculation based on rated efficiency and rated power via internal function in PumpMon
2. For other motors, e.g. canned motor pumps (***PolyAct*** = TRUE, ***ConvAct*** = FALSE):
→ Calculation based on motor characteristic line by means of a polynomial of the 4th order; the coefficients ***K0*** to ***K4*** must be supplied by the manufacturer of the motor/pump.
3. If the frequency converter delivers both the electrical and the mechanical power directly l (***PolyAct*** = FALSE, ***ConvAct*** = TRUE):
→ no further parameterization required, besides the linking of ***PoMech*** as mentioned above, eventually normalization by ***PoMechOffs*** and ***PoMechFact***

Parameters for standardized motors:

- Rated power ***PoRate*** (in faceplate, view „parameters“, or in CFC)
- Rated efficiency ***Eta*** (in faceplate, view „parameters“, or in CFC)
- For all three power variables (electric, mechanic and hydraulic power) the low range for the faceplate bar graphs (**MO_PVLR_Elekt**, **MO_PVLR_Hydr**, **MO_PVLR_Mech,** normally = 0) and the high range (**MO_PVHR_Elekt**, **MO_PVHR_Hydr**, **MO_PVHR_Mech**, normally a little bit above rated power) have to be specified in CFC.

For all motor types:

- Number of pole pairs **PolePair** (in CFC)

For motors with variable speed

- Take away tick mark „constant speed in faceplate view „parameters“, or parameter ***ConstSpd*** = „variable“ (FALSE) in CFC
- Rated speed ***SpdRate*** (in faceplate, view „parameters“, or in CFC)
- Please refer to hints on slip correction in [2.] !

4.2.2 Parameters of Pump

- Characteristic lines for delivery height, power and efficiency (in faceplate view "ParTable", or in case of need in CFC)

The characteristic lines can have up to 15 interpolation points; if not all of them are used, the spare values must be set equal to the last valid value, to fulfill the requirement of monotonically increasing x-values.

The values on the x-axis (flow) do not need to be equally spaced. The time base for the flow values must be specified (***TimeBase*** = 3600s when scaling in m^3/h).

The extrapolation above and below the range of the characteristic line is horizontal, i.e. if the flow value is smaller than the leftmost interpolation point, the first y-value is written to the output, if the flow value is larger than the rightmost interpolation point, the last y-value is written to the output.

<u>Teach function:</u> The characteristics from the pump documentation should normally be used. If the documentation is not available or the current status of the pump is to be used as a reference (e.g. because the sensor placement is not ideal), the individual pump operating points can also be approached manually and the values determined here for the flow rate, delivery height, power, and efficiency can be used as interpolation points for the characteristic lines. The teach function can be used as a tool for entering the interpolation points for the characteristics. The actual values calculated for the delivery height, power, and efficiency are used as points in the characteristics. The values can then be corrected manually if required.

Sometimes only a part of the characteristic is relevant for operation in a continuously operated plant, and even for teaching it is difficult to move to other operating regions. In such cases it is sufficient to teach only the section of the characteristic that is relevant for operation. Attention: the requirement for monotonously rising x-values must be fulfilled anyway! In order to achieve a reasonable optical display of the characteristic, the line can be continued consistently to the left and to the right of the teached section, and filled with plausible values.

- Minimal flow ***MinFlow*** (in faceplate, view „parameters“, or in CFC)
- Rated flow ***OptFlow*** (in faceplate, view „parameters“, or in CFC)

For cavitation monitoring additionally:

- Characteristic line for NPSH value (in faceplate, view "ParTable", if needed in CFC)

The NPSH characteristic has its own interpolation points for flow (***FlowNp1***, ..., ***FlowNp15***), because this characteristic line cannot be teached at all.

- Diameter of intake socket and pressure side socket (in faceplate, view „parameters“, or in CFC)

In case of bypass around pump:

- Bypass (set tick mark in faceplate, view „parameters“, or in CFC).
  In a pump with bypass, the measured flow is not correct, because the flow through the bypass is not measured. In this case the function block will calculate an estimated flow value based on mechanical power. Therefore the monitoring of deviations from the power characteristic is no more possible.

4.2.3 Parameters of Pumped Medium

- Density (in faceplate, view „parameters“, or in CFC)

For cavitation monitoring additionally:

- If medium is different from water 0 – 100ºC: Antoine coefficients ***AntA, AntB, AntC, AntFact*** ; or for external calculation of vapor pressure (***Antoine*** = FALSE) → linking of input ***P_Vapor*** [bar] (CFC only)

4.2.4 Message Parameters for Dry Run, Blockage and Power Deviations

- Power limits for the detection of blockage ***PoBlk*** and dry run ***PoDryRun*** (in faceplate, view „tolerances“, or in CFC)

In case of dry run, the valve at the suction side is closed, there is no fluid inside the pump, the flow will be zero and the electrical power decreases to a minimal value (typically < 30% of rated power).

WARNING	**In case of dry run the pump bearings will be overheated, and will be destroyed in a short time. If there is no fluid at all inside of the pump, there can be sparks emitted between rotor and housing, which must be completely avoided especially in explosion protection areas. The PumpMon function block is able to detect a pump running dry during operation in time, but if the pump is started without any fluid, the reaction of the PumpMon will be too late. Therefore in explosion-proof areas, additional action is to be taken to avoid starting a pump without fluid, e.g. application of a binary flow detector ("Liquifant") in the suction pipe.**

In case of blockage, the valve at the pressure side (or both) are closed and the flow is zero as well. The value of the electric power is low, but not as low as in case of dry run, because there is still some fluid circulated inside the plump (typically < 40% of rated power).

WARNING	**During blockage, the friction heat generated by the pump motor cannot be transported away by the pumped medium, and the medium is heated. This situation is very dangerous, especially if the valves on both sides of the pump are closed. If the evaporating temperature of the medium is reached, and the resulting pressure cannot find a way out, a steam explosion can blast the pump housing and cause mortal danger.**

- Suppression time ***SuppTime***, during this time after motor startup, all messages of the function block are suppressed (in faceplate, view „parameters“, or in CFC).
- For each of the deviations from the characteristic lines, there is a limit for the maximal relative deviation: ***Tol_Height, Tol_Power***, ***Tol_Eta***, ***Tol_NPSH***, all in [%], and an associated time delay: ***T_Height, T_Power***, ***T_Eta***, ***T_NPSH*** (in faceplate, view „tolerances“, or in CFC). A message is generated if the limit is violated for more than the specified time delay. Proposal for default values: ***Tol_Height, Tol_Power, Tol_Eta*** = 5%, ***Tol_NPSH*** = 0,5m; ***T_Height***, ***T_Power, T_Eta, T_NPSH*** = 300 sec. During operation, application specific individual values for these limits must be found. Hint: the upper limit of 50s for

the time delays is only implemented in the faceplate. You can enter higher values in CFC or modify the limit in the *.pdl file of the faceplate.

- For each of the power variables (electrical, mechanic and hydraulic), there is monitoring of upper and lower alarm and warning limits, including message suppression according to PCS 7 standards. Limits and message suppression can be operated in faceplate view "tolerances" with access level "higher process controlling", or in CFC.
- All limit monitoring functions include hysteresis. The hysteresis of electrical, mechanic and hydraulic power can be modified in faceplate view "tolerances"; the other hysteresis values can only be modified in CFC.

5 Evaluations for Plant Asset Management

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.

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

5.1 Maintenance Request

A maintenance request announced by a maintenance message is not generated by the PumpMon function block itself, but by the associated AssetMon function block [3.]. The AssetMon is a universal proxy function block for mechanic and process assets in the Maintenance Station of 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 Electronic Device Description (EDD) containing the master data of the pump is attached to the AssetMon block, allowing to access the pump like an intelligent field device in the context of asset management.

5.1.1 Specify Pump Master Data

In order to generate the EDD for a pump, you need a so called PLT-ID [3.].

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. In the tree structure CFC > DATA_OBJECTS > CFC >, select AssetMon 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”`.
7. The parameter assignment screen form is closed.
8. Select the TAG object and then `“Tools > SIMATIC PDM > Create PLT-ID”`.

You can then assign parameters for the generated PLT-ID at the associated parameter "PLT_ID". Note: The PLT-IDs cannot be changed or deleted individually.

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

5.1.2 Linking and Parameterization of AssetMon Function Block

Inside the PumpMon block, a histogram of load distribution over time is generated, and a histogram of cavitation states. The number of operating hours in a certain load range is visualized as bar height in the histogram. The bar height (number of operating hours) of each bar is available as a separate output variable at the PumpMon function block.

Please check the NPSHa limit where pump damage starts to occur. Typically this will start if the actual NPSHa value is below the required NPSHr value, i.e. the deviation from the NPSHr characteristic is negative. Therefore, take a sum of the related output variables ***DevNpsh1+DevNpsh2+DevNpsh3*** and link it the input variable ***PV_1*** of the associated AssetMon function block, as shown in Figure 3-1 by the Add4P block "CaviTime".

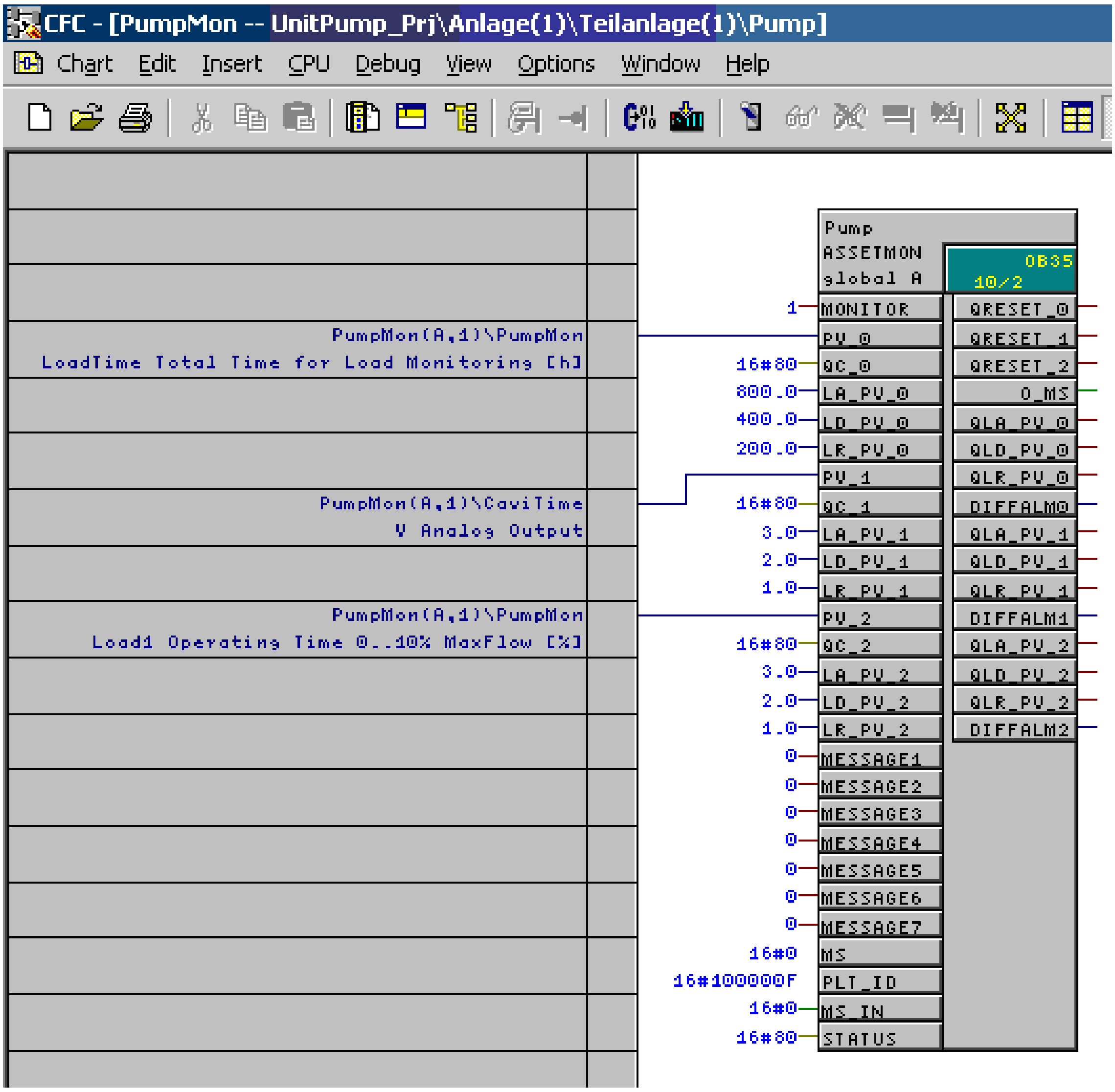

Figure 5-1: Linking of AssetMon function block for a pump

Define the limits for Maintenance Request ***LR_PV_1***, Maintenance Demand ***LD_PV_1*** and Maintenance Alarm ***LA_PV_1*** such that after the specified number of hours in cavitation the desired maintenance request is generated.

If you know that the pump after a certain amount of operating hours in overload or underload typically needs maintenance, you can link further analog inputs e.g. ***PV_2*** of AssetMon to the respective histogram output variables e.g. ***Load1*** of PumpMon and define alarm limits for the operating hours.

If the pump needs maintenance after a defined number of operating hours, independent of operating conditions, you can take the overall number of operating hours since initialization of the load statistics from the output PumpMon.***LoadTime***, and you do not need a separate counter for operating hours. In this case, the load statistic must be re-initialized after each maintenance action (by clicking the reset button in the faceplate), in order to reset the counter to zero.

5.2 Stress-minimized Operation

For the operation of centrifugal pumps you need sufficient suction head (pressure on the suction side of the pump), such that the pump is running in intended operation state, i.e. with less than 3% loss of delivery height due to cavitation. For pumps that are in danger of cavitation from time to time, the application of a dedicated anti-cavitation controller can be helpful.

The aim of the approach described in [4.] is "stress-minimized" and energy efficient operation of pumps (“stress-minimized operation“, SmO), based on established pump monitoring. An additional, supervisory function can exploit the information on actual stress intensity in current operation, and interact with the conventional control logic, such that stress-intensive operating conditions are reduced or completely avoid by optimal process control. The intervention of the SmO-function is restricted to reasonable limits. A compromise between the main targets of process control and the target of stress minimization is searched.

The idea is to establish an anti-cavitation controller in parallel to the flow controller, which is acting on the same manipulated variable [8.].

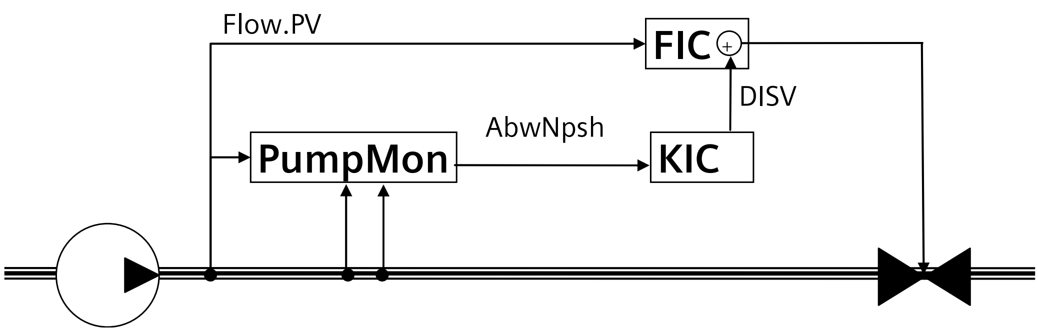

Figure 5-2: Principle of anti-cavitation controller

The controlled variable of the anti-cavitation controller is the deviation of NPSHa from a limit critical for the emergence of cavitation.

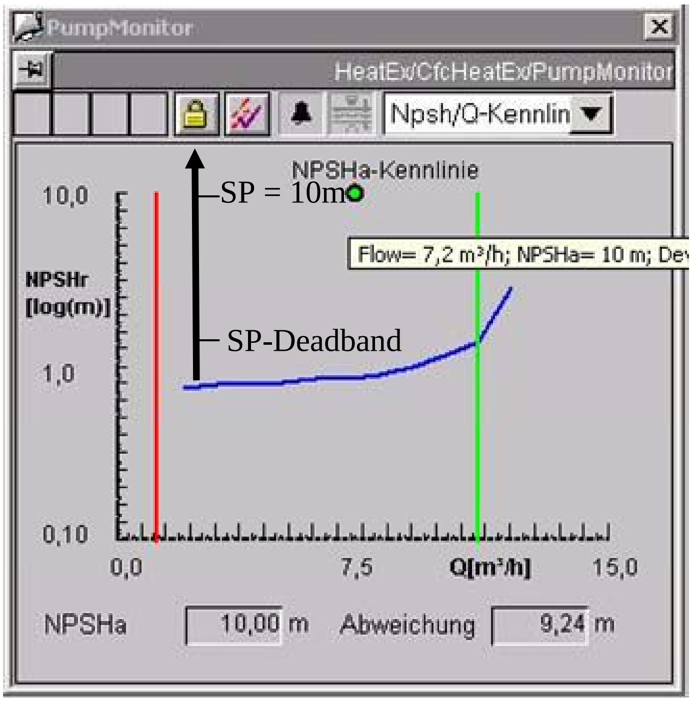

Figure 5-3: NPSH characteristic line, coordinate axis for controlled variable and setpoint of anti-cavitation controller

For example, the NPSH setpoint is set constant to 10m above the NPSHr line. The anti-cavitation controller is a proportional-only controller with a deadband of 8m. By doing without integral action you can avoid that the controller must be switched to tracking mode if he has no access to the actor. The deadband makes sure that the anti-cavitation controller does not interfere with the flow controller during normal operation. However, if the NPSH deviation is approaching the critical limit, the anti-cavitation controller will begin to intervene, by closing the valve at the pressure side a little bit. Due to this intervention, flow will decrease, and the actual NPSH value moves horizontally to the left, which means that the distance to the critical limit will increase.

As soon as the anti-cavitation controller becomes active, the integral action of the flow controller is frozen in the respective direction, such that the flow controller can not work with its own integral action against the anti-cavitation controller

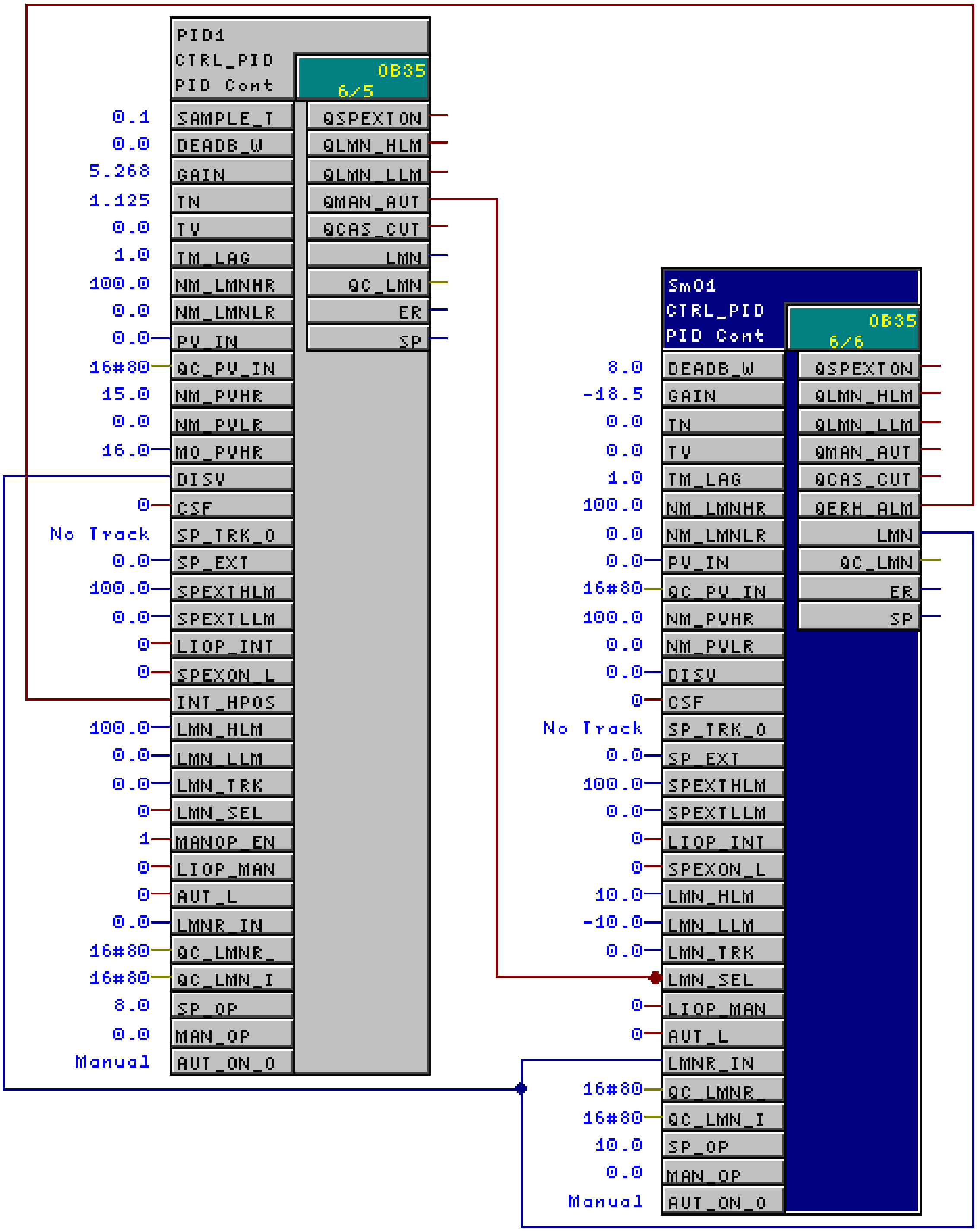

Figure 5-4: CFC chart of anti-cavitation controller "SmO1" in connection with the flow controller FIC (here PID1)

6 Application Example

There is a PCS 7 solution template for automation of a pump unit in [8.]. The pump unit allows generating a controlled flow using a fixed speed pump.

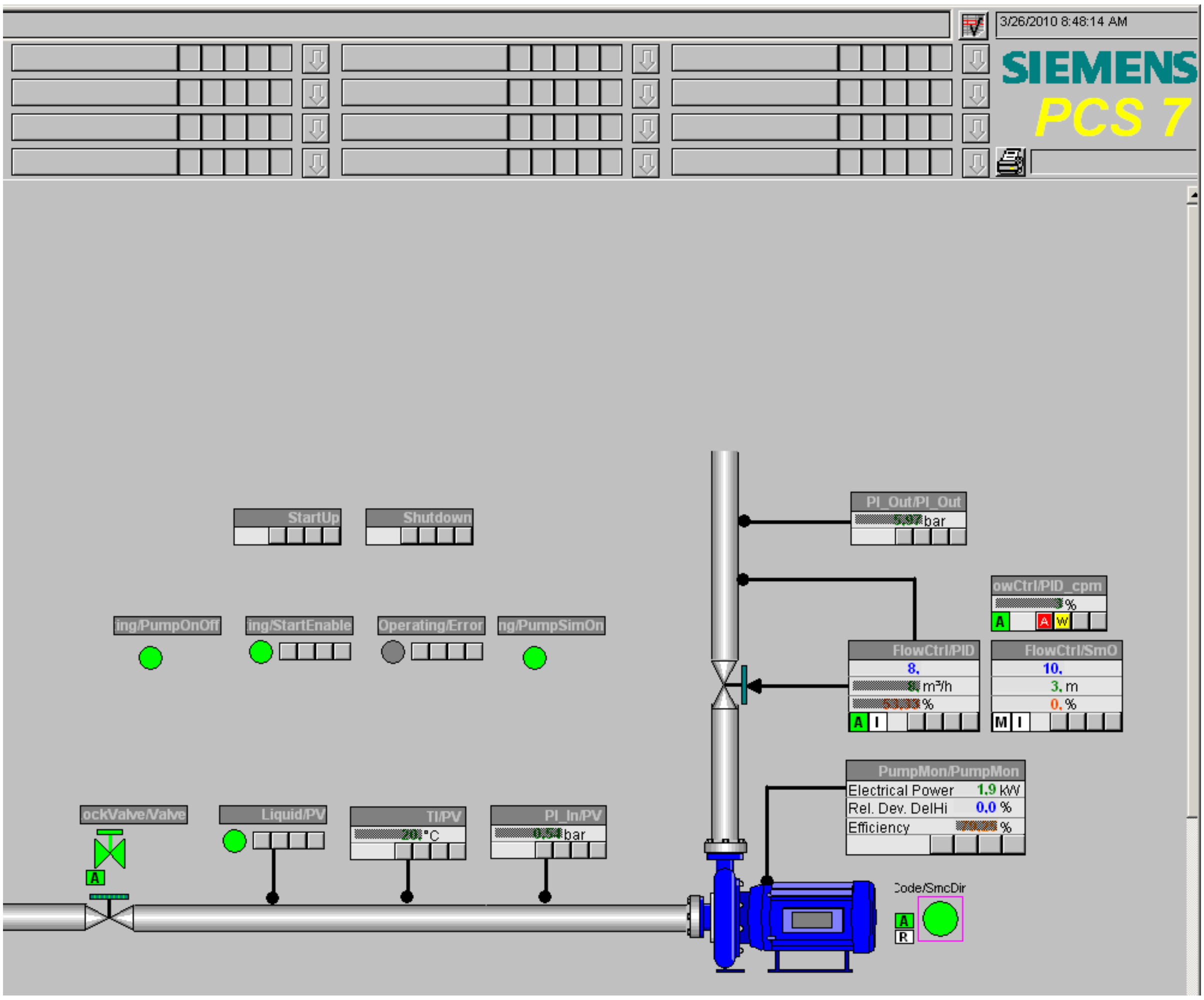

Figure 6-1: PCS 7 solution template pump unit

The pump unit includes the following functions and the related measurement tag instances:

- Control of pump motor via direct starter Simocode
- PI flow control using a controlled valve at the pressure side
- Lock valve at the suction side
- Interlock logic, c.f. section 3.2.1
- Pump monitoring using the PumpMon function block
- Maintenance management using the AssetMon function block, c.f. section 5.1
- Sequential function control (SFC) for organized startup and shutdown of the pump unit
- Optional: Stress-minimized operation to avoid cavitation (c.f. section 5.2)

6.1 Realization of Interlocks

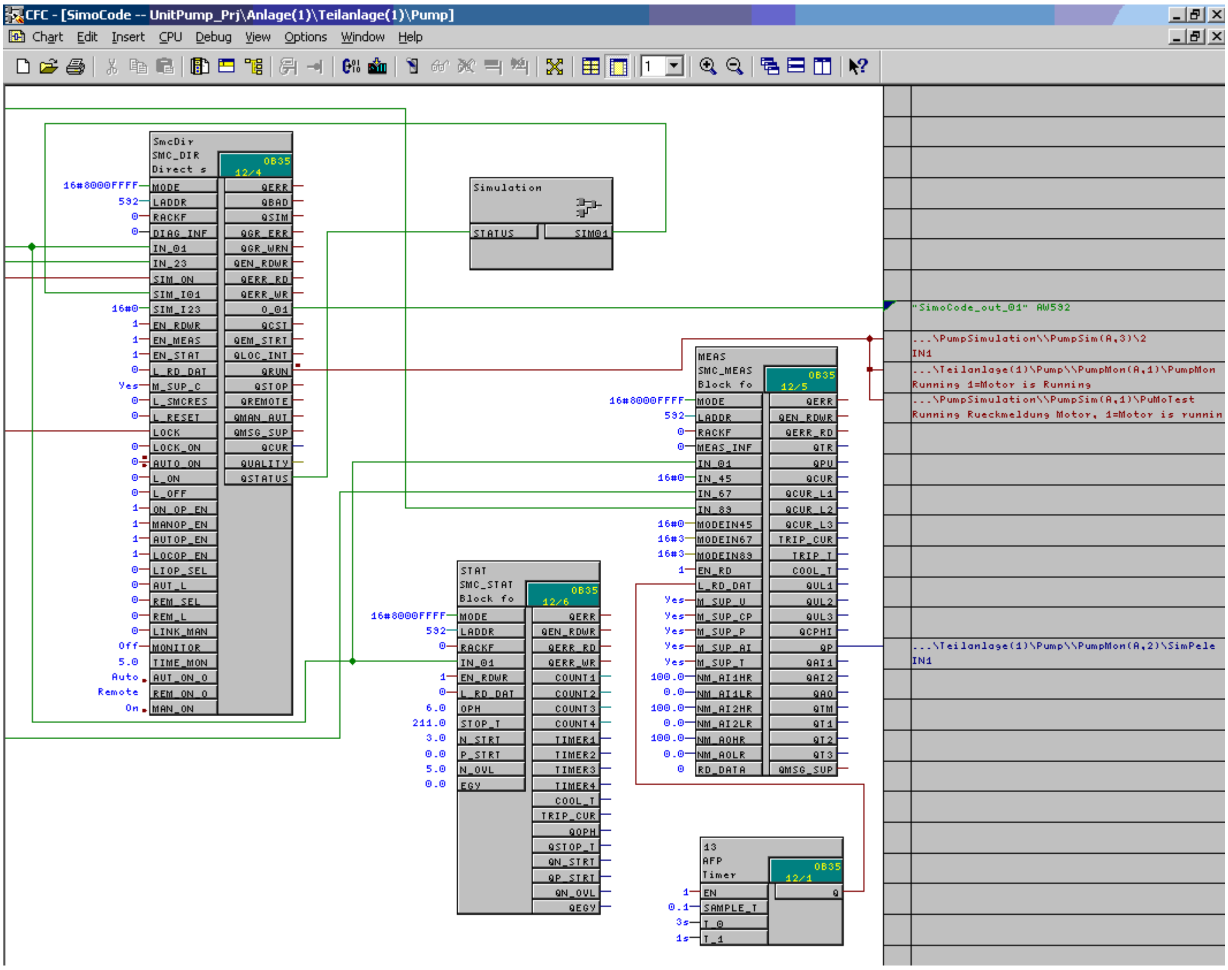

Figure 6-2: Pump motor control via Simocode, the interlocks are acting on the input variable LOCK of function block SmcDir

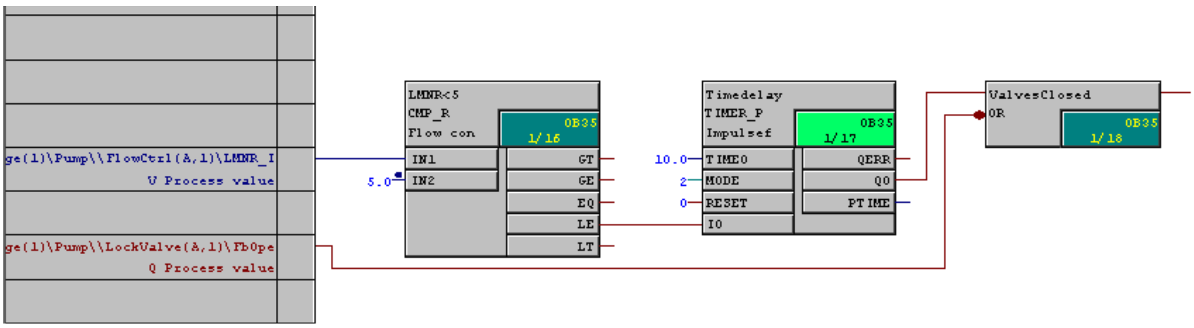

Figure 6-3: Interlocking the pump drive if lock valve at suction side is closed (not Valve.FbOpened), or control valve at pressure side is closed to much (FlowControl.LMNR_I < 5) for some time

6.2 Simulation of Different Operating States

6.2.1 Intended Operation

During intended operation the actual delivery height is at the expected level, i.e. at the characteristic line.

When modifying the setpoint of the flow controller, the actual operating point is moving along the characteristic line to the left or to the right. Temporary deviations during the transient response are no reason for concerns, because the characteristic line is only a model of steady state behavior. Concluding from this, alarm delays for deviations from characteristic lines have to be specified long enough, such that the pump itself and all related measurement values reach a steady state after a setpoint step before the alarm becomes active.

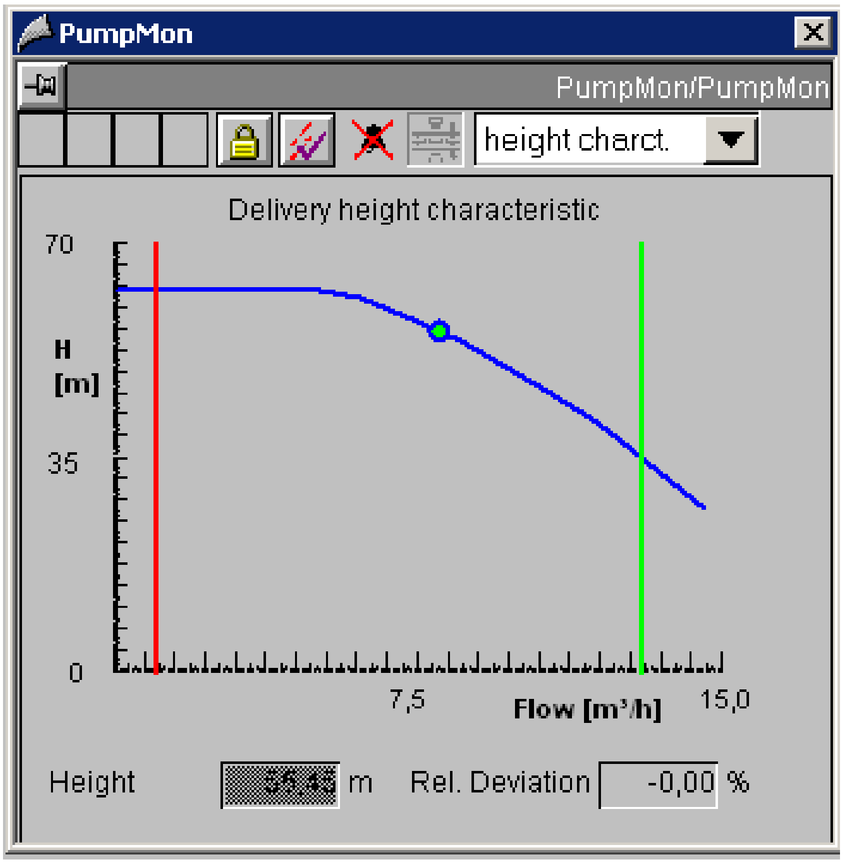

Figure 6-4: Delivery height characteristic during intended operation. The actual delivery height (green dot) is at the expected line.

6.2.2 Delivery Height Losses by Wear and Tear or Gas Conveyance

In the simulation example, decreasing pump efficiency can be simulated by reduction of delivery pressure. For this, you can "falsify" the scaling factor ***PumpMon.P_OutFactor*** artificially, i.e. reduce it from 1 to 0.8.

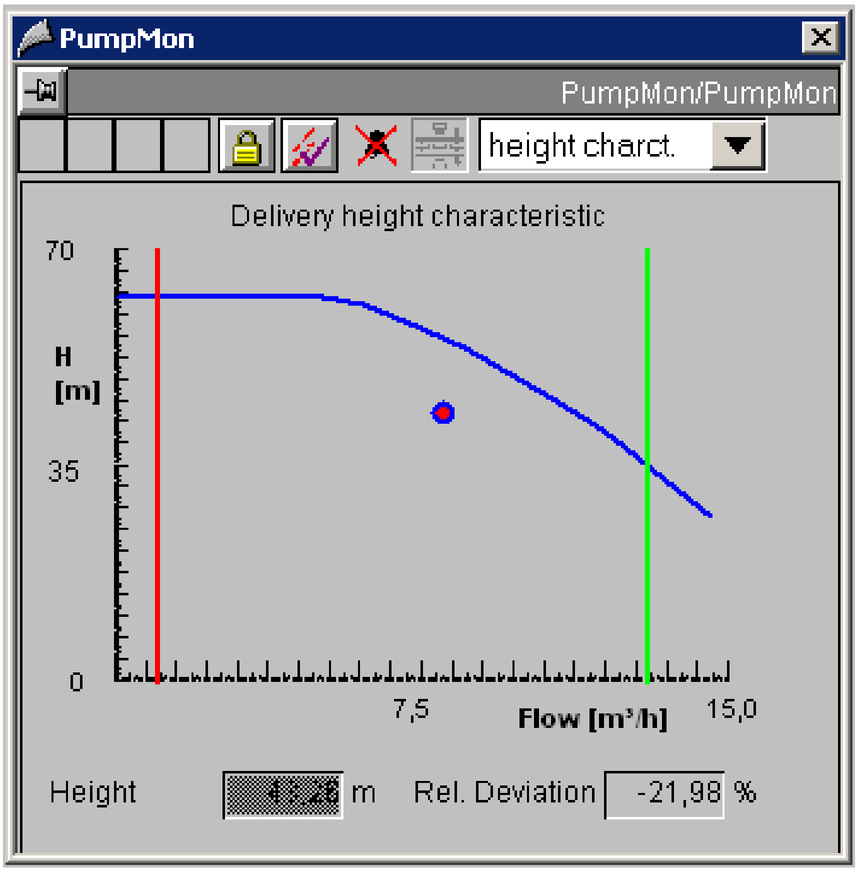

Figure 6-5: Delivery height losses in characteristic line view

You observe that the actual operating point moves away downwards both from the delivery height characteristic and from the efficiency height characteristic and it changes color from green to red. A warning message "Delivery height deviates from characteristic..." and "Pump efficiency deviates from characteristic..." is generated.

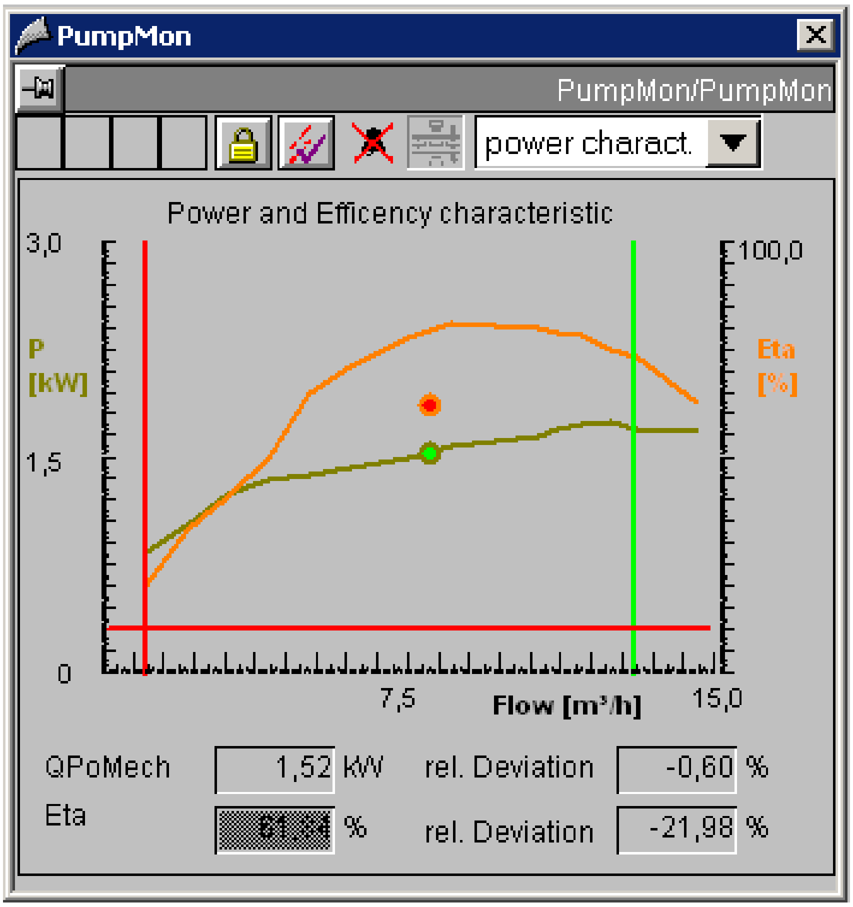

Figure 6-6: Efficiency losses in characteristic line view.

Electrical power is still at the olive green characteristic line (Figure 6-6), 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.

The following causes for delivery height losses have to be considered:

- Gas conveyance,
- Cavitation or
- Wear and tear.

You check the Npsh-characteristic to make sure, if cavitation really is the cause (c.f. section 6.2.3).

A worn crack can be detected by trend recording of the deviation ***DevDelHi*** from the delivery height characteristic over a longer time range. The deviation will increase slowly but consistently.

On the other hand, delivery height losses caused by gas conveyance can appear suddenly, and disappear suddenly. Causes for gas conveyance have to be searched at the suction side, e.g.

- Suction of air at leakages with depression,
- Excess rotation speed of agitators in upstream tanks, or
- Chemical reactions that generate gases.

Special case incorrect direction of rotation: If the motor was mounted incorrectly and rotates in the wrong direction, you observe both a strong delivery height loss (>40%) and a small deviation from the power characteristic (<20%). This case is signaled by a warning message "Wrong direction of rotation".

6.2.3 Cavitation

In the simulation example cavitation can be simulated by reduced suction pressure. You falsify the scaling factor ***PumpMon.P_InFactor*** artificially, i.e. reduce it stepwise from 1 to 0.4.

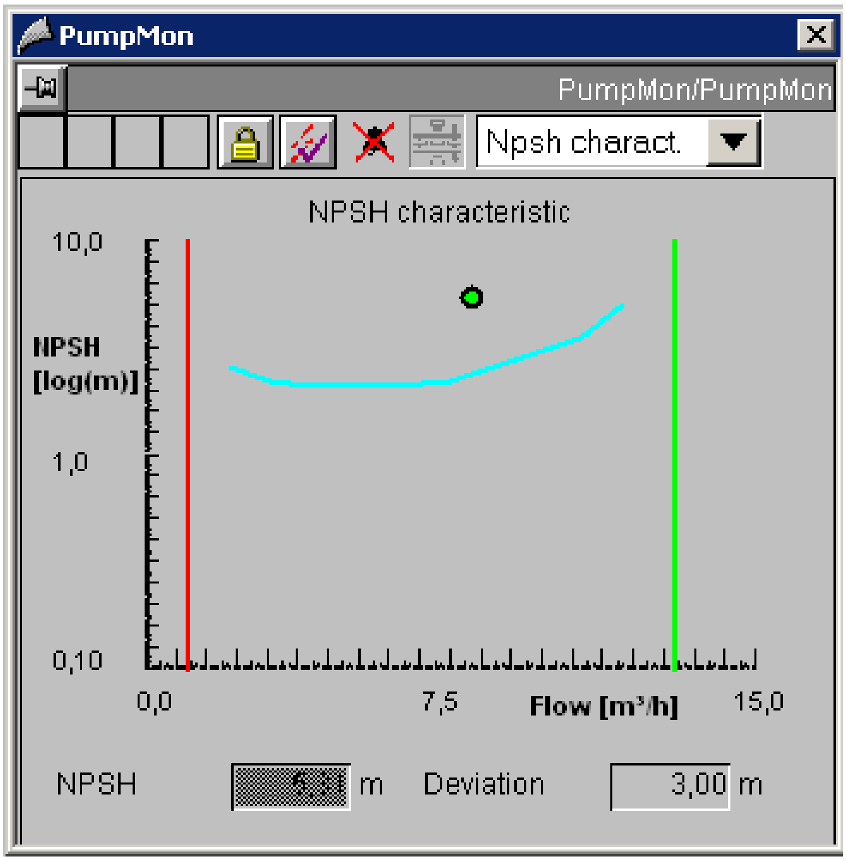

Figure 6-7: Npsh-characteristic during intended operation of the pump.

The available suction pressure (interpreted in meters hydrostatic head) is 3m above the suction pressure required for this flow according to the characteristic line.

You then observe that the actual NPSH operating point is approaching the cavitation limit from upside, and shortly before it will cross the limit, will change color from green to red. Approaching the cavitation limit is interpreted as an early warning of cavitation danger, and alerted by a warning message „Npsh-value is too low“. After falling below the limit line, an alarm "Cavitation!" is generated.

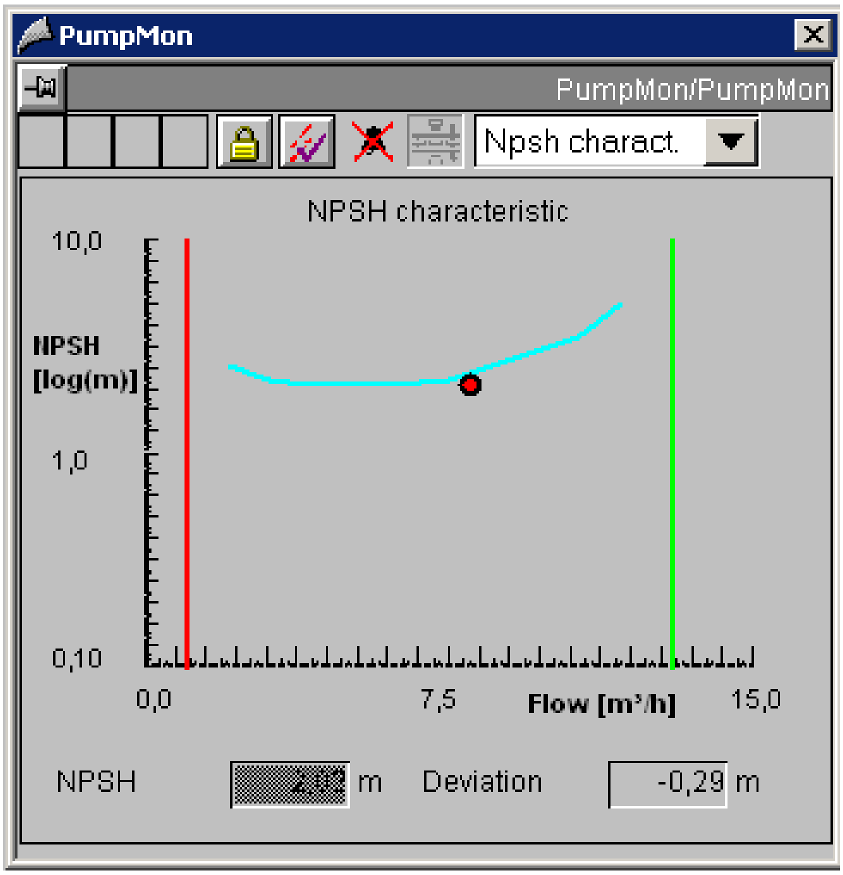

Figure 6-8: Npsh characteristic line during cavitation.

The available suction head is 0.29m below the required suction head for this flow according to characteristic line. At the same time, pump delivery height is crashing. Cavitation will erode the pump rotor in the course of time.

6.2.4 Dry Run

In the simulation example dry run (c.f. section 4.2.4) can be simulated by closing the suction side valve. Take the lock valve in manual mode and close it. The pump will be shut down by interlocks of pump unit.

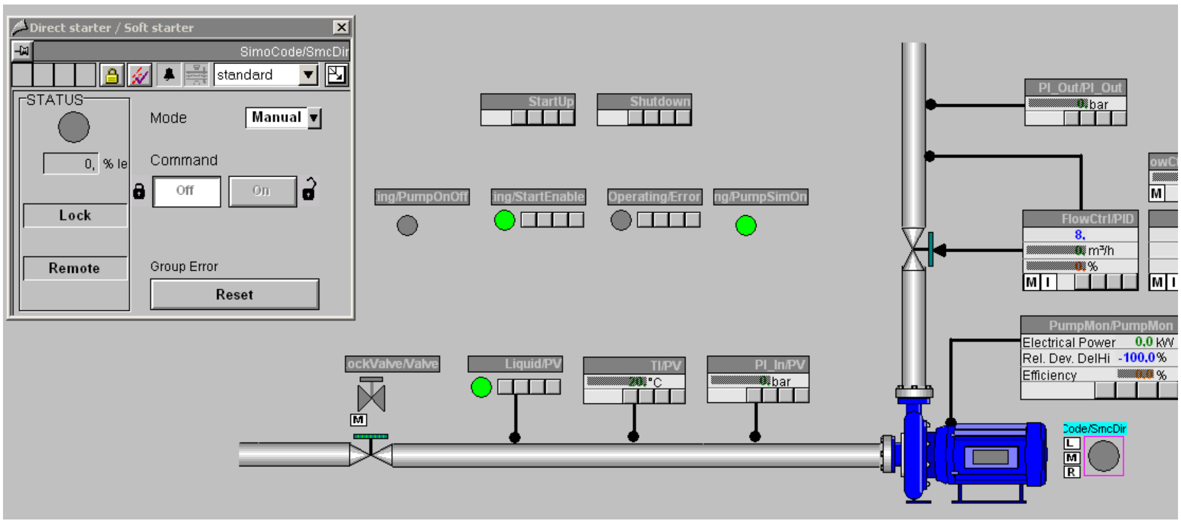

Figure 6-9: Automatic interlock shutdown of pump unit caused by dry run, visible in Simocode faceplate of pump drive by status "Locked" and motor "Off". The reason is the closed suction side valve (now grey instead of green like in Figure 6-1)

Additionally, the shutdown can be triggered by evaluation of the respective binary output ***PumpMon.Q_DryRun*** , but the direct logical connection to valve state must be implemented due to safety reasons anyway. PumpMon can naturally detect dry run even when the suction side valve is open, if e.g. the suction side tank has fallen empty.

6.2.5 Blockage

In the simulation example, blockage (c.f. section 4.2.4) can be simulated by closing the pressure side valve. Take the flow controller FlowControl/PID in manual mode, and specify a value of 3% for the manipulated variable. After some seconds the pump will be shut down by interlocks of the pump unit, similarly to the case of dry run.

Additionally the shut down could be triggered by evaluation of the respective binary output ***PumpMon.Q_Blk***. This way the shutdown will be triggered even if blockage cannot be detected by valve position, because it is caused e.g. by a foreign particle in the pipeline.

6.2.6 Overload Operation

In the simulation example overload operation of the pump drive, caused by excessive friction of bearings, can be simulated by excessive electric power intake. Modify the scaling factor ***PumpMon.PoElectFactor*** artificially, e.g. increase it stepwise from 1 to 1.8.

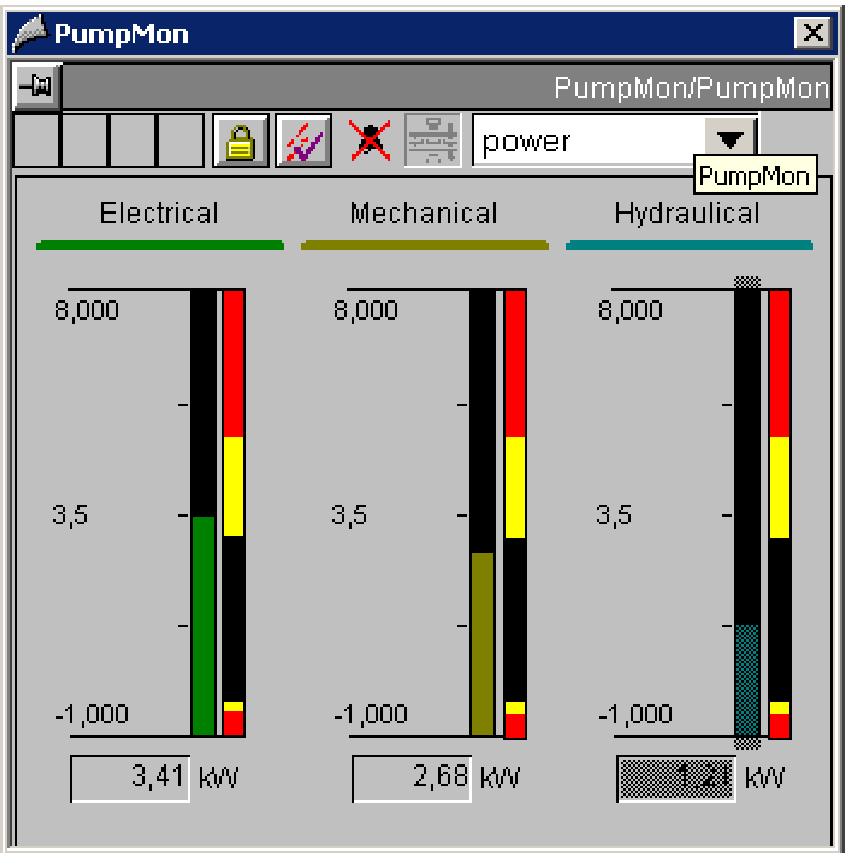

Figure 6-10: Overload operation in bar graph of power values

Together with electric power, the mechanic power calculated by the motor model will also increase. If one of the related limits is violated, a warning or alarm message like e.g. "Electrical Power HH-Alarm" will be generated.

7 Summary

The function block PumpMon calculates the following variables, that are not directly measured:

- Delivery height
- Mechanic power
- Hydraulic power
- Pump efficiency
- NPSH value
- Statistical distribution of flow values ("load distribution")

Pump diagnosis works with the following logic to detect faulty operating conditions:

- **Blockage**: is detected from electric power. This correlation is independent of motor model. Increased robustness by signal filtering.
- **Dry run**: is detected from electric power. This correlation is independent of motor model. Increased robustness by signal filtering.
- **Faulty operation** (out of intended operation): is detected from delivery height loss (specified deviation from delivery height characteristic).
- **Cavitation**: is detected from delivery height loss in conjunction with NPSHa value (if safety margin of 0.5m to NPSHr characteristic is violated).
- **Pump wear and tear**: can be detected externally
  - With respect to cavitation: summation of operating hours in cavitation.
  - With respect to worn crack: enduring deviation from delivery height characteristic (e.g. 48h permanent deviation), that is not caused by gas conveyance.
- **Overload**: is detected from electric power.
- **Bad pump efficiency**: is detected from deviations of actual pump efficiency (hydraulic / mechanic power) from efficiency characteristic.

	Flow	Diff.-pressure via pump	Electr. power	Pressure in front of pump	Temp. medium	Density	Vapor pressure
Blockage	**(x)** [1]		**x** [2]				
Dry run	**(x)** [1]		**x** [2]				
Gas conveyance	**x**	**x**				**[x]** [4]	
Cavitation	**x**	**x**		**x**	**[x]** [4]		**[x]** [5]
Pump wear	**x**	**(x)** [3]	**x**				
Overload			**x**				
Bad pump efficiency	**x**	**x**	**x**				

Table 7-1 Correlation of measurable variables and detectable problems

Legend:

x	Measurement required (mandatory)
(x)	Measurement helpful, but not mandatory
[x]	Depends on application - see remarks

Remarks:

[1] Not urgently required, but useful for additional plausibility check.

[2] Is used for calculation of mechanic power.

[3] In delivery height characteristic more significant than in power characteristic.

[4] If not constant, sometimes as additional value from flow measurement field device.

[5] If Temperature is not constant (then specify constant value); the function block includes calculation of vapor pressure by Antoine equation. In other cases, vapor pressure must be calculated from temperature by external CFC functions and linked to the respective PumpMon input.

8 Literature

[1.] PCS 7 PumpMon - Condition monitoring for centrifugal pumps. Product definition sheet. I IA SE SH, Erlangen, Aug. 2008.

[2.] Online help function block, I IA SE SH, Erlangen 2008,

[3.] Online help function block, AssetMon, PCS7 ES V7.0.1, I IA AS RD Khe, 2008.

[4.] Pfeiffer, B-M., Grieb, H., Bettenhausen, K. D.: Prozessnahes Performance-Management - vom Plant Asset Management zur optimierten Betriebsführung. VDE-Kongress, Aachen, Okt. 2006. Tagungsband 2, VDE-Verlag, Berlin, S. 325-330.

[5.] Müller-Heinzerling, T., Grieb, H., Pfeiffer, B-M.: Ganz schön clever - Nicht-intelligente Komponenten in das anlagennahe Asset Management einbinden. atp 11/2006, S. 56-61.

[6.] Pirsing, A., Grieb, H. , Pfeiffer, B-M., Müller-Heinzerling, T.: Zerstörerische Blasen - Preiswerte Kavitationsüberwachung für Kreiselpumpen in der Wasserwirtschaft. A&D-Kompendium 2007/2008.

[7.] Müller-Heinzerling, T., Grieb, H., Pfeiffer, B-M.: Asset Management für mechanische Anlagenkomponenten – Unkomplizierte Überwachung von nicht-.

[8.] Müller, P., Pfeiffer, B-M.: Anwenderdokumentation zum PCS 7 Solution-Template Pump-Unit. Siemens I IA&DT ATS 32, Nov. 2007.

9 History

Version	Date	Changes
V1.0	April 2010	1st release

Table 9-1 History