

EXPERT SYSTEMS IN ULTRASONIC FLOW METERS

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1 INTRODUCTION:

Custody transfer ultrasonic gas flow meters are the cash registers of the companies. These cash registers should measure accurately. To determine the accuracy two aspects are addressed:

- The calibration: The deviation of an ultrasonic flow meter to the national standards under ideal flowing conditions.
- The installation effects: The increase of uncertainty due to the “non-ideal” on-site installation, as described in the international standards like ISO17089 and OIML R137.

A third aspect, the change in uncertainty of the ultrasonic flow meter while in operation, is often overlooked. For example; already limited fouling on the bottom of the pipe can give an additional uncertainty of 0.2%. Other aspects like severe flow profile changes due to partly blockage of a flow conditioner, damaged transducers or high levels of ultrasonic noise also play an important role during the operational time of an ultrasonic flow meter.

The solution often used is re-calibration. Unfortunately re-calibration involves high costs (downtime, handling & transport, calibration) and still it is unclear at what moment, the observed shift during calibration, occurred during its operational time. As such it is unclear how to financial compensate for the observed shift.

The true solution is diagnostics. This provides a continuous monitoring on the performance of the meter and can detect fouling, severe flow profile distortions and high level of ultrasonic noise in an early stage. Corrective actions can be taken long before significant measurement errors occur.

Ultrasonic flow meters do have a large number of diagnostic parameters. The latest generation of meters is even equipped with ultrasonic paths that are not used for flow measurement at all, but are solely used to generate diagnostic information assuring the user that his billing is still ok.

A drawback of this is, that with the growing number of diagnostic parameters, the relations between these and the process conditions are getting increasingly complex (see figure 1).

In addition to this, also the quality of a diagnostic parameter can vary largely with the process conditions. At the end, the user is faced with a system that, without additional intelligence, only a highly trained expert can understand.

To remedy this, a diagnostic expert system has been developed, presenting the user not only with just a warning but with easy understandable information.

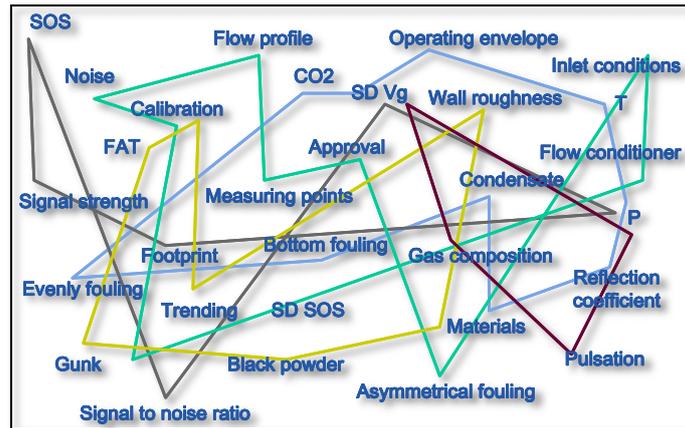


FIGURE 1: EXAMPLE OF DIAGNOSTIC PARAMETERS AND THEIR INTERRELATIONS.

This expert system:

- Analyses the performance of a meter
- Present the user with clear and easy understandable information
- Present a choice of expertise levels (from secretaries to nerds)
- Generates a standard performance report
- Is easy accessible (web based).
- Has flow computer functionality

2 THE ICEBERG SPECIFICATIONS

Since the introduction of the ALTOSONIC V12, KROHNE addressed the issue of accuracy as being the tip of an iceberg. Comparing the specifications of different ultrasonic flow meters, all manufacturers show similar specifications, this despite the obvious differences in their designs:

Uncertainty	$\leq \pm 0.5\%$ of measured value, un calibrated
	$\leq \pm 0.2\%$ of measured value, high-pressure flow calibrated (relative to calibration laboratories)
	$\leq \pm 0.1\%$ of measured value, calibrated and linearized
Repeatability	$\leq \pm 0.1\%$

TABLE 1: TYPICAL SPECIFICATIONS (TIP OF THE ICEBERG)

This is only a small part of the whole story. As with the iceberg, the larger part that cannot be seen lies below sea level and can be dangerous. table 1 only show the results of an ultrasonic gas flow meter during its calibration. The more important parts lie below sea level:

1. Installation effects: The transferability of the calibration curve, obtained under almost ideal conditions in the calibration facility, to the actual conditions in the field.
2. The impact of fouling and corrosion on the meter performance.

The installation effects were investigated in autumn 2008 at the OGE/Ruhrigas test facility in Lintorf, Germany. The results of all flow disturbance tests according to OIML R137 and ISO 17089 showed that the ALTOSONIC V12 performs excellently under all conditions and that the quality of the meter's calibration curve can be transferred to the field with a minimal additional uncertainty ^[1].

The ALTOSONIC V12 is the first ultrasonic meter to be able to be installed in applications having only a 5D straight upstream inlet length where uncertainties better than $\pm 0.2\%$ are required. As a result, the ALTOSONIC V12 is world-wide the first ultrasonic gas flow meter receiving the prestige OIML R137 Class 0.5 approval. Other ultrasonic flow meters complies to OIML R137 Class 1.0, indicating that they are two times more sensitive to installation effects than the ALTOSONIC V12.

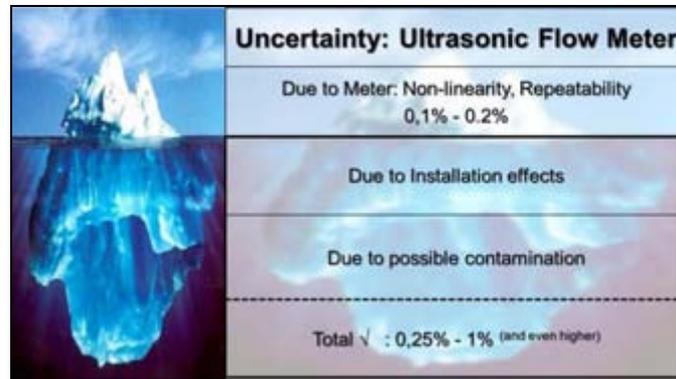


FIGURE 2: THE ICEBERG SPECIFICATIONS

The second issue, impact of fouling and corrosion was extensively tested in July 2010 also at the OGE/Ruhrgas test facility in Lintorf, using two 6" ALTOSONIC V12 meters in series. The impact on the error curve and the parameters such as velocity, gain, speed of sound, etc.... were measured with different types of fouling such as bottom, wall and transducer fouling, liquid contamination, wall roughness, etc.... This resulted in a good understanding of the key diagnostic parameters to detect and analyze the various types of fouling ^[2]. Each type of fouling had its own characteristic combination of parameters; a combination that can be used by the meter to determine the type of fouling.

3 DIAGNOSTIC TOOLS OF AN ULTRASONIC FLOW METER

3.1 DIAGNOSTIC PARAMETERS

The primary parameter of an ultrasonic flow meter is of course Flow. Next to this the ultrasonic flow meter produces a huge amount of diagnostic parameters such as:

- The velocity of each individual path,
- The speed of sound of each individual path,
- The pulse acceptance of each individual path,
- The amplification (gain) of a received acoustic pulse at each transducer,
- The signal to noise of a received acoustic pulse at each transducer.

For the 6 path ALTOSONIC V12 this already results in 42 parameters.

3.2 DIAGNOSTIC VALUES

Above mentioned diagnostic parameters are available after each measuring cycle, which is typical about 10 times per second. An ultrasonic flow meter, in general, will present this data only once a second.

For stable diagnostic evaluation it is useful to use averaged values over a time frame of about 100 seconds or more. Within this time frame also the observed minimum, maximum and standard deviation can be used for diagnosis.

For each of the above described diagnostic parameters the following values are available:

- Average,
- Standard deviation,
- Minimum & Maximum

This results in a total of 168 values

3.3 ADDITIONAL DIAGNOSTIC FEATURES OF THE ALTOSONIC V12

Beneficial for the KROHNE ALTOSONIC V12 with respect to diagnostics is the use of reflecting paths and the presence of a dedicated vertical diagnostic path ^[4].

By reflecting the presence of cross flow or swirl is compensated in plane giving a very robust measurement under disturbed flow profile conditions ^{[1], [3]}. This resulted in the only ultrasonic flow meter with OIML R137 Class 0.5. A second major advantage of using reflective technology is the possibility to interrogate the inside of the pipe wall. Long before serious measurement failures occurs the influence of roughness and fouling is detectable ^[2]. Other techniques, like profile factor can also detect these kind of issues but are at least an order of magnitude less sensitive.

The second major benefit of the ALTOSONIC V12, is the presence of a dedicated diagnostic path. This path is vertically orientated to detect localized fouling at the bottom. Any effect on this path does not affect the flow measurement. Its weighting factor is set to zero, and as such it is not used in the overall velocity calculation.

Other aspect with respect to using reflective techniques is that a longer path gives a more accurate and stable reading. It has however also a drawback; A longer path length gives more attenuation of the acoustic pulse. As such reflecting technology is less suitable for high CO₂ and low pressure applications. Solution for these type of applications are using more powerful transducers or use pulse compression techniques.

4 DIAGNOSTIC MONITORING.

For diagnosis the diagnostic parameters that are mentioned in chapter 2, needs to be continuously monitored and checked. The monitoring can be done in different ways.

4.1 ABSOLUTE MONITORING.

The first type of monitoring is absolute monitoring. A value of a parameter is checked to a certain warning and alarm limit. If the value is lower (or higher) than its limits, a warning or alarm is given.

In figure 3 an example is given of an absolute monitoring type. In this case the Pulse Acceptance of path 6 (diagnostic path) is monitored over time. The Pulse Acceptance is the ratio between the number of pulses transmitted and the number of pulses received and accepted. Pulses may occasionally get deformed while traveling through the gas (turbulence). A deformed pulse may give an incorrect time of flight measurement and should be rejected resulting in a lower Pulse Acceptance. For Pulse Acceptance the applicable absolute warning and alarm limits are 40% and 20%.

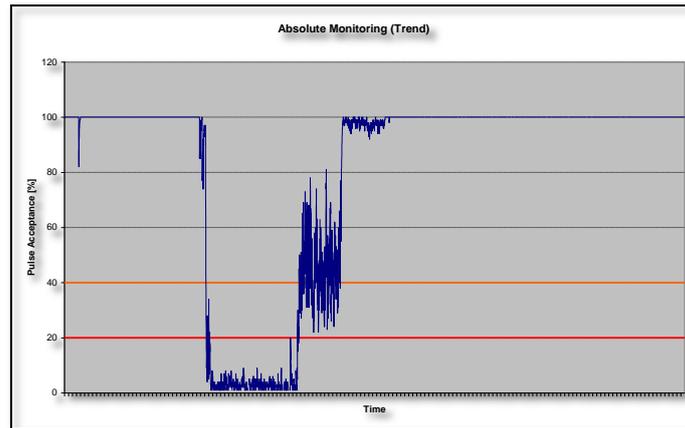


FIGURE 3: EXAMPLE ABSOLUTE MONITORING

Due to passing of a slug of liquid the Pulse Acceptance drops to almost 0% (see figure 3). As a result the alarm will be active. After a few minutes the Pulse Acceptance increases up to around 40%. The alarm will become inactive and a warning will be given.

4.2 MONITORING RELATIVE TO THE PATHS.

Another way of monitoring a value of parameter is relative to the paths.

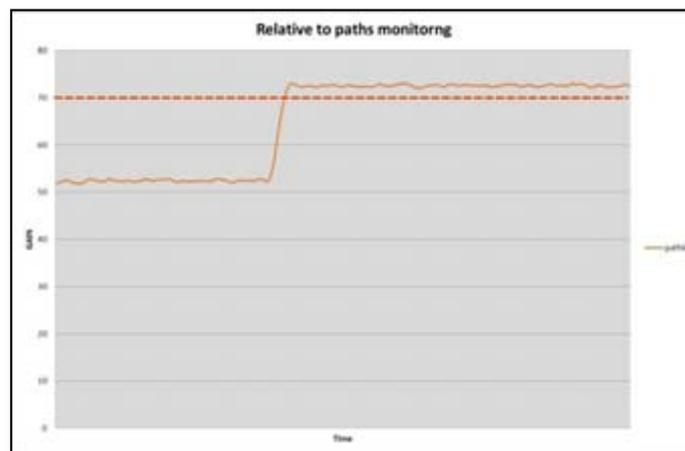


FIGURE 4: EXAMPLE RELATIVE TO PATH MONITORING (PATH 6)

In figure 4 the gain of path 6 is presented over time. The gain is the amplification factor of a pulse to a certain norm level. High gain indicates low signal strength, low gain values indicate a high signal strength. figure 4 shows that path 6 had a gain of about 55 dB at a certain moment the gain increased significantly passing a warning level of 70 dB. The conclusion could be a failure on path 6.

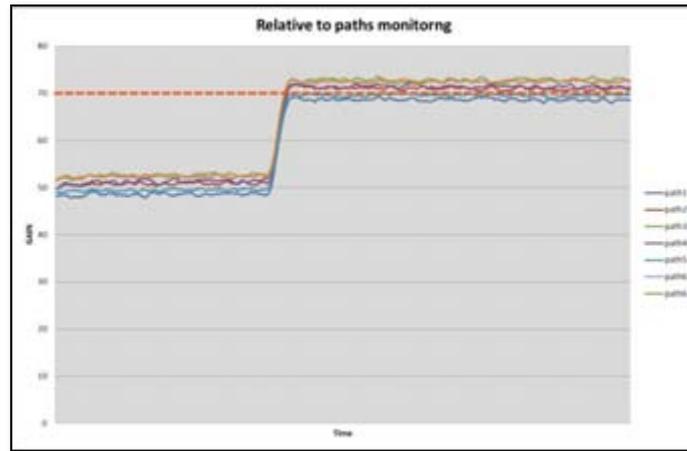


FIGURE 5: EXAMPLE RELATIVE TO PATH MONITORING (ALL PATHS)

However if all paths are evaluated (as presented in figure 5) all paths seems to behave similar. The initial conclusion, failure on path 6, seems to be incorrect. Or all paths have a problem or another effect has caused this behavior. In this case the increase was due to a pressure drop in the system.

Instead of monitoring these values in an absolute way the gain can be presented in a relative way whereby the differences between the paths are observed. A new parameter could be the ratio of the path gains or in this case the difference of the gains (logarithmic scale, dB).

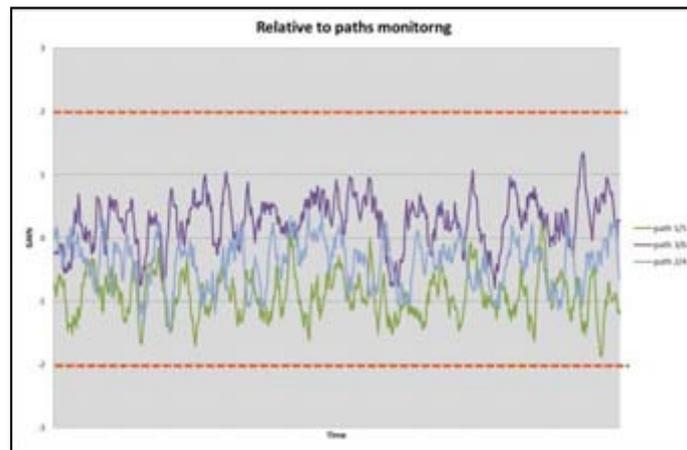


FIGURE 6:EXAMPLE RELATIVE TO PATH MONITORING

In figure 6 the difference of the gain of path 1 & 5, 2 & 4 and 3 & 6 including the warning and alarm limits (warning limit difference between paths = 2 dB). The choice for this combination of paths is because these paths are similar positioned in the ALTOSONIC V12. The difference between similar paths should lie close to zero and if not changing the conclusion can be made that the meter is functioning correctly.

4.3 MONITORING RELATIVE TO THE VELOCITY

A number of diagnostic parameters will change if the velocity changes. It is known that for example the flow profile changes. The change of this profile has an effect on the individual velocity readings of the paths. This velocity dependency is application specific.

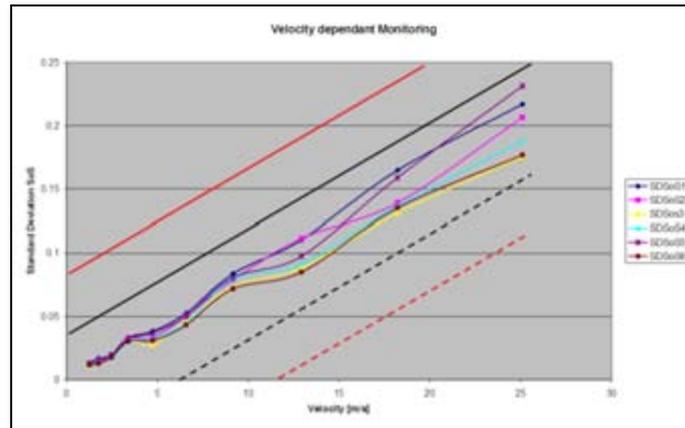


FIGURE 7: VELOCITY DEPENDANT MONITORING

In figure 7 a not so obvious parameter, the standard deviation of the speed of sound, is shown as function of the velocity. By setting warning and alarm bandwidths around the presented curve this parameter can be used for diagnostic.

4.4 APPLICATION DEPENDENT MONITORING.

Because an ultrasonic flow meter is based on time of flight also the speed of sound can be measured. In natural gas applications, gas chromatographs (GC) and temperature and pressure sensors are used to calculate the energy and compressibility of the gas. The same information, gas composition, temperature and pressure can also be used to calculate the speed of sound.

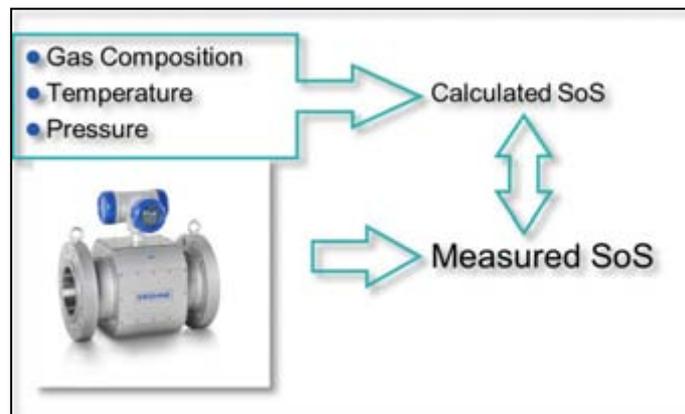


FIGURE 8: APPLICATION DEPENDENT MONITORING (SoS)

Comparing the calculated speed of sound to the measured speed of sound gives a powerful diagnostic feature. This feature is used to check the ultrasonic flow meter but can also check the gas chromatograph, temperature and pressure sensor. In a situation that a deviation between measured and calculated speed of sound is present and all the speed of sound measurements of the individual path are identical to each other, it is advisable to first check the temperature, pressure, gas composition and the sampling system.

5 SETTING UP A DIAGNOSTIC SYSTEM

To create a diagnostic system the parameters as mentioned chapter 3 and the different monitoring types as mentioned in chapter 4 needs to be combined. The gain as discussed in paragraph 4.2 was monitored in an absolute way (gain < 70 dB) and in a relative way (difference gain 1 & 5 < 2 dB). Each type of monitoring of a parameter is called a CHECK. Each CHECK can have three statuses; Good (Green), Warning (Orange) and Alarm (red). In figure 9 the used CHECK's of KROHNE Care are presented.

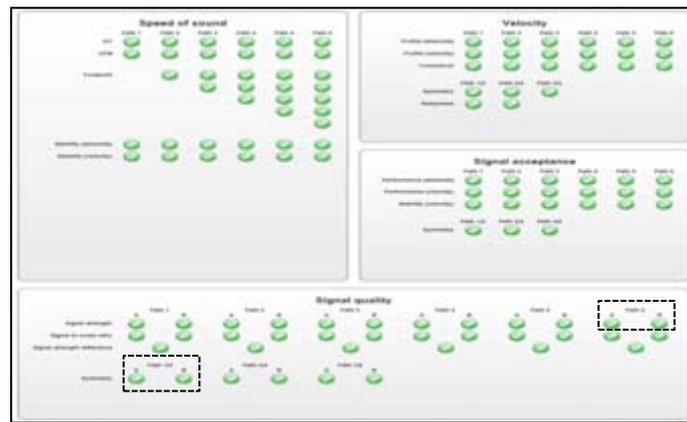


FIGURE 9: ALL CHECKS OF KROHNE CARE

The discussed CHECK's "gain absolute" and "gain difference 1 & 5" are separately emphasized in figure 9.

By combining different CHECK's a STATUS is created. As such a more condensed presentation of the health status of the ALTSONIC V12, is given.



FIGURE 10: STATUS'S OF KROHNE CARE

In figure 10 the results of the CHECK's are condensed to path STATUS's (path 1 to 6) and parameter STATUS's (speed of sound, velocity, signal acceptance and signal quality). Finally an overall health STATUS is required. This Master status will be a single marker. If colored green, the meter operates correctly. If colored orange some failures have occurred but the ALTOSONIC V12 is still operating within its custody transfer limits, corrective actions should be planned. If colored red, a serious failure has occurred and immediate action is required. The master status can be found in the top left corner of figure 10 and will also be visible at the start up screen of the on-board web page as presented in figure 15.

6 SETTING UP AN EXPERT SYSTEM

6.1 FROM DIAGNOSTIC SYSTEM TO EXPERT SYSTEM

In chapter 5 the diagnostic system is presented. Multiple CHECK's compare the values to the predefined warning and alarm limits. A specialist can, based on the CHECK's and STATUS's, deduct the problem and advice corrective actions. For an expert system, this advice should be given by the system itself. KROHNE Care has taken this next step.

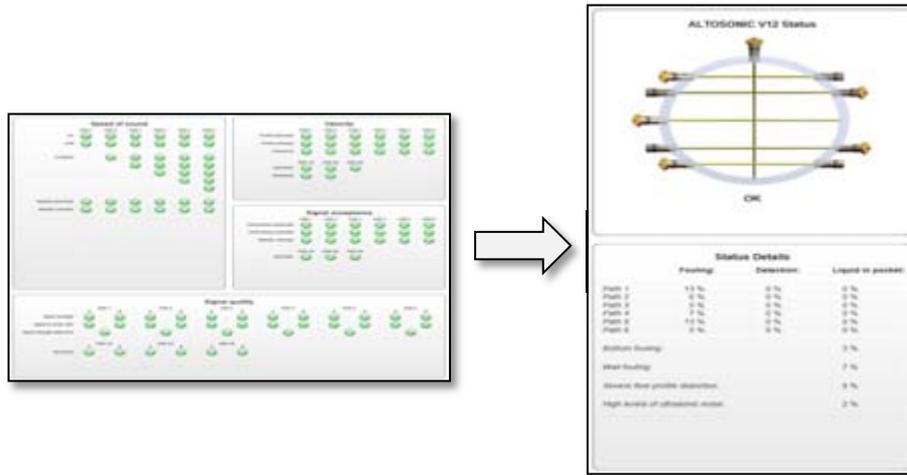


FIGURE 11: FROM DIAGNOSTIC SYSTEM TO EXPERT SYSTEM

The right side of figure 11 shows the condensed information of all the CHECK's into clear understandable advice. At the top, the ALTOSONIC V12 and its paths are visualized. Below that, different causes are presented with their likelihood of occurrences.

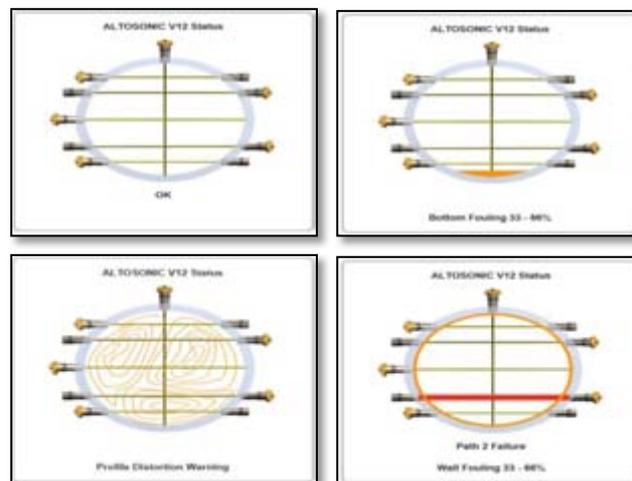


FIGURE 12: VISUALISATION OF FAILURES

In figure 12 different examples are given on the visualization of failure modes. The failure type, warning or alarm, is presented with different colors. The orange color of the profile distortion in the bottom-left corner of figure 12 indicates that the flow profile is distorted but still within acceptable (custody transfer) limits. In the bottom-right corner of figure 12 multiple failures are given. The likelihood of occurrences of these failures will give more background information.

Status Details			
	Fouling:	Detection:	Liquid in pocket:
Path 1	20 %	1 %	1 %
Path 2	97 %	46 %	45 %
Path 3	14 %	1 %	1 %
Path 4	50 %	1 %	7 %
Path 5	21 %	1 %	1 %
Path 6	14 %	0 %	1 %
Bottom fouling:			10 %
Wall fouling:			35 %
Severe flow profile distortion:			28 %
High levels of ultrasonic noise:			2 %

FIGURE 13: STATUS DETAILS OF FAILURES

The likelihood of occurrences (status details) of the situation in the bottom-right corner of figure 12 can be seen in figure 13. The failure of path 2 is likely due to fouling. Wall fouling gives a likelihood of 35% which is just above the warning level. Advice in this case would be to clean path 2. While cleaning path 2 check the inside of the pipe for fouling. Some fouling may be present but it is expected that the wall fouling warning is also caused by the fouling alarm of path 2.

6.2 APPLICATION DEPENDENT OPTIMIZATION OF THE EXPERT SYSTEM

An expert system with basic settings is always available. These settings are based on the dry calibration (FAT) and, if applicable, on the flow calibration. To further optimize the expert system application specific settings should be added.

In paragraph 4.3 the velocity dependent monitoring was presented and the changing velocity profile as a function of the velocity was discussed. The flow profile is however not only velocity dependent but also application dependent. To optimize the expert system, this application specific behavior should be registered. For this KROHNE Care uses an auto-commissioning function.

During commissioning of an ultrasonic flow meter it is very useful to test the meter under pressure and over its full operating range. In practice commissioning is done mostly under non-flowing and pressurized conditions. Sometimes, a flow can be given but never over a full flow range. Nevertheless this information is required to fully optimize KROHNE Care. During the startup phase of the ultrasonic flow meter, different flows will pass through it. By using the Auto-commissioning of KROHNE Care these flows and its related parameters will be stored automatically. This information will not be used immediately while it cannot be guaranteed that the information stored is done under normal, clean and non-failure conditions. After confirmation of the correctness of the data, the velocity dependent data will be implemented in a reference file. This reference file will check all the velocity dependent parameters. The expert system is now optimized to the customers application.

6.3 EASE OF USE OF EXPERT SYSTEM

KROHNE Care has several unique features which makes it easy to use.

6.3.1 WEB BASED MONITORING

Krohne Care is a fully web based system. From any laptop or personal computer via internet the ALTOSONIC V12 can be checked by typing its IP-address into a web browser.



FIGURE 14: OVERVIEW SCREEN KROHNE CARE

In figure 14 the overview (start) screen of KROHNE Care is presented. On the top-right side the overall master STATUS is presented. Below the overall master STATUS bars are presented for indicating the actual flow, velocity, Speed of Sound, Pulse Acceptance, temperature and pressure. Left from the master STATUS a graph presents the master status value over the past few days. Below this graph the audit and alarm log is presented. Also the visualization of the ultrasonic flow meter as presented in paragraph 6.1 is present. Below that, general information of the application is presented together with the totals. On the left side, a tree is present to navigate through the different screens.

The next two pages are presented in figure 15. The in paragraph 5 and 6 discussed CHECK's and STATUS's are shown on these pages.

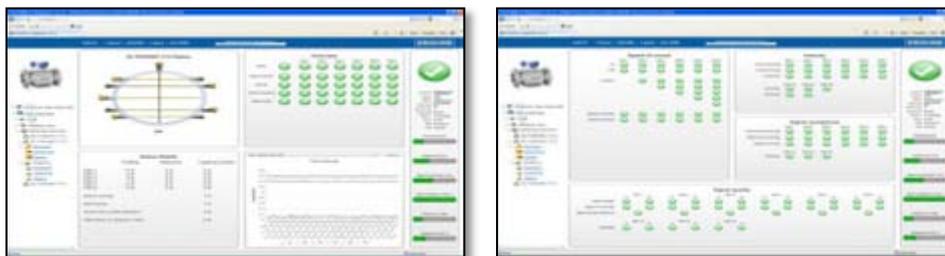


FIGURE 15: EXPERT & DIAGNOSTIC PAGE OF KROHNE CARE

Of course next to the diagnostic data also live data can be reviewed via internet.

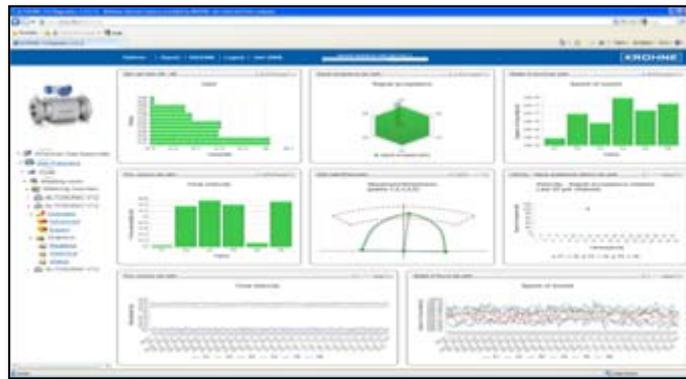


FIGURE 16: LIVE DATA, WEB BASED AVAILABLE

In figure 16 the parameters like Gain, Signal to Noise, Pulse Acceptance, Velocity and Speed of Sound can be presented in multiple ways; bar, column, line and spider graphs. Also trend charts are present for different selectable parameters. In the middle a visualization of the skewness and sharpness of the profile is shown.

6.3.2 REPORTING

For audit trail purposes reporting of current status of a flow meter is important. KROHNE Care makes also this reporting feature, web based available



FIGURE 17: KROHNE CARE REPORTING

Using the “report” button, a report is generated from the actual status but also historical data of the past days, weeks or even months can be presented in two pages as shown in figure 17. The report can be checked, under signed and stored for audit trail purposes.

6.3.3 DATA STORAGE AND TRANSFER

6.3.3.1 Data Storage

All parameters and diagnostic data are stored on a 2 GB SD Card. Storage is done “live” and “event based”.

With live data storage the actual parameters and diagnostic parameters including CHECK's and STATUS's are stored every minute. After 15 minutes the minutes value are averaged and are stored. In the same way hourly averages and daily averages are stored. As such 10 years of daily data, and 365 days of hourly data, 100 days over quarterly hour data and 24 hours of minute data is stored.

The event based storage stores data based on different triggers. The trigger can be a STATUS change or an Alarm. When triggered, the diagnostic data and 30 seconds of live data before and after the trigger is stored. As such the Alarm or STATUS change can be reviewed afterwards.

Another event based storage is the discussed auto commissioning function (par. 6.2). For optimization this data needs to be retrieved. This data transfer can be done web based

6.3.3.2 Data Transfer

To store the data locally as described in paragraph 6.3.3.1 is an important feature. Still it would be useful to transport this data to a laptop or PC as backup or for further analysis. Especially the event based data storage during the commissioning phase needs to be reviewed for optimization of the expert system. This can be done web based.

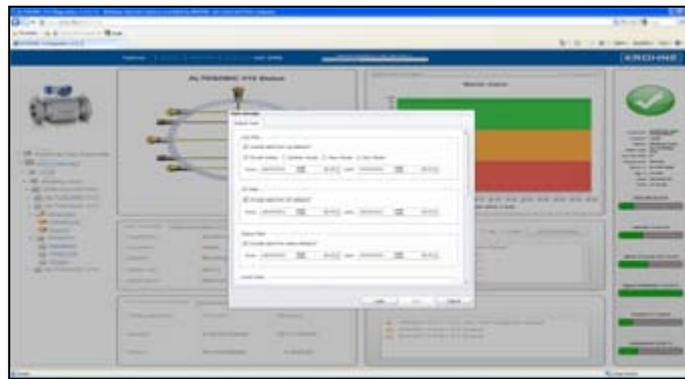


FIGURE 18: WE BASED DATA TRANSFER

Using the “storage button” a screen pops (figure 18). The type of data that needs to be transferred can be chosen (event, log, commissioning or GC data). Also the time frame can be chosen. Via internet the data is transferred from the ALTOSONIVC V12 to the laptop or PC. Also uploading, especially for the application specific reference table, is via internet possible.

6.3.4 HISTORICAL REVIEW

Aside from the above discussed use of “data transfer for further review”, the historical data analysis can also be done directly via internet. In figure 19 the web based daily averaged path statuses are presented of our demo unit from 10 December 2011 until 23 April 2012. This demo unit is situated in our R&D facility in the Netherlands and errors were deliberately created as part of a long term test of KROHNE Care.

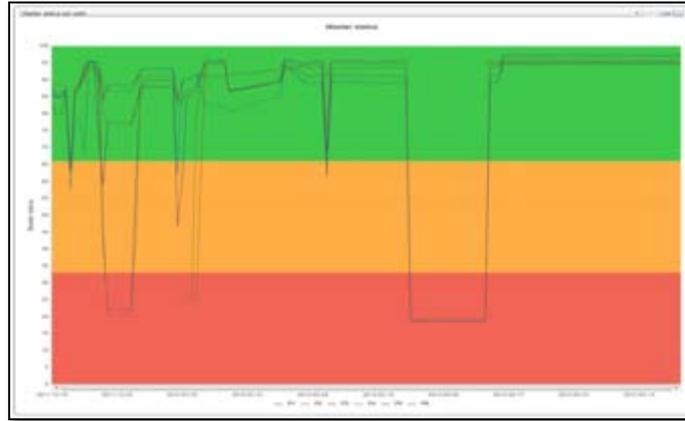


FIGURE 19: PATH STATUS FROM 10 DECEMBER 2011 TO 23 APRIL 2012

Within the same time frame the Parameter Status's (SoS, Signal, Velocity & Pulse acceptance) can be checked as well as the Expert Status's (wall fouling, bottom fouling, Noise levels, flow profile distortion).



FIGURE 20: PARAMETER STATUS AND EXPERT STATUS

It is possible to zoom in and check hourly or even quarter hourly average statuses in a specific time frame.

A second step of reviewing the stored data is by:

- State Histogram: How often in a certain time frame was a parameter in alarm, warning or correct operating mode for a specific path (see figure 21)
- Historical trend line: A trend graph of a specific parameter in a certain time frame including Standard deviations, minimum and maximum values reached.
- And more like, graphs to review velocity and pressure dependent historical behavior.



FIGURE 21: EXAMPLE OF STATE HISTOGRAM.

The extensive web based historical review options gives powerful tools to do remote review without the need to transfer the data to a local PC (par. 6.3.3).

7 FLOW COMPUTER FUNCTIONALITY

KROHNE Care was initially developed as an expert system for the ALTOSONIC V12. One of the diagnostic tools was to check the measured Speed of Sound to a calculated speed of sound as such the requirement to connect to a GC, Temperature and Pressure sensor was present. A special dedicated diagnostic board was developed which aside from the diagnostic feature also has a flow computer functionality. KROHNE Care can communicate through Modbus with a gas chromatograph. Temperature and pressure sensors are read through HART protocol. The energy and compressibility can be calculated based on different methods / standards. The normalized flow can be determined and normalized totalizers are available making KROHNE Care not only an Expert system but also a flow computer. The flow computer functionality however is non-custody transfer. It can only be used in non-custody transfer applications or as a backup system for a flow computer.



FIGURE 22: ALTOSONIC V12 EXPERT SYSTEM WITH FLOW COMPUTER FUNCTIONALITY

8 CONCLUSION

To continuously guarantee the correctness of your cash register a continuously monitoring system is required. Ultrasonic flow meters have a significant amount of diagnostic parameters which can be used for continuously diagnosis of the ultrasonic flow meter. A diagnostic system only tells you if certain parameters are outside its limits, it does not tell you what the problem is. With KROHNE Care the next generation of diagnostics expert systems is introduced. It is an easy to use, web based expert system with flow computer functionality which takes continuously monitoring of an ultrasonic flow meter to a next level.

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