EVALUATION REPORT E 1956 X 14

Published by Evaluation International September 2014

Index Classification: 1.2

SWINTON Technology
Condition based monitoring (CBM) system
'PROGNOSIS'

Manufacturer: **SWINTON TECHNOLOGY LTD**
UK

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EVALUATION OF

SWINTON Technology
Condition based monitoring (CBM) system
'PROGNOSIS'

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Report No E 1956 X 14

Index Classification 1.2

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Appendix I – Manufacturer’s Safety & Quality Questionnaire

Appendix II – Manufacturer’s Data Sheet “Standard Prognosis Displays”

SWINTON condition based monitoring (CBM) system ‘PROGNOSIS’

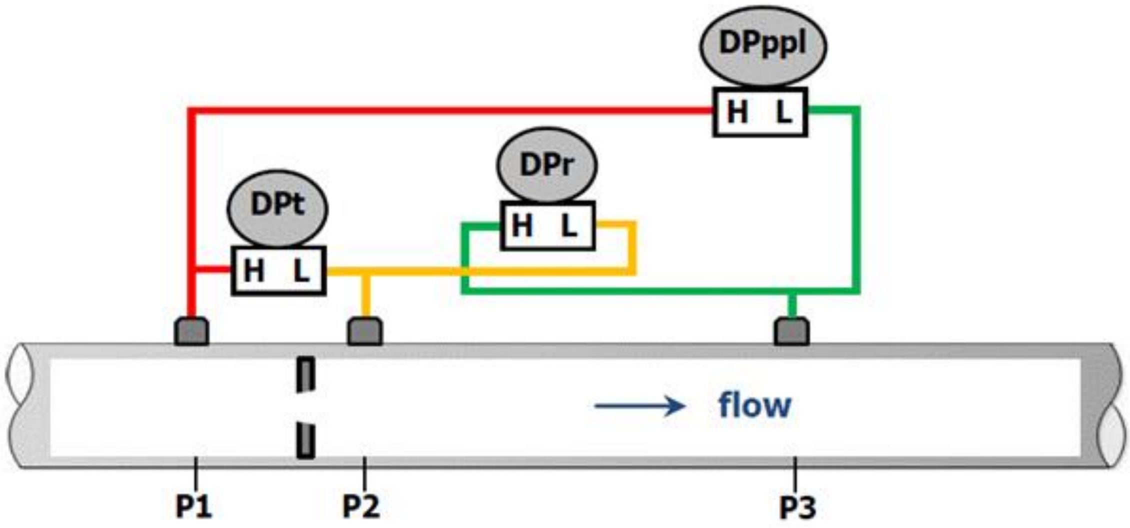

Figure 1 – Simplified orifice meter with DP instrumentation sketch illustrating the three DP measurements required for PROGNOSIS (Source: SWINTON Technology).

By utilising a third taping (P3) downstream of a meter body, it is possible to read three DP measurements (Figure 1).
These three DP measurements are the core of the PROGNOSIS system, unlocking the full self-diagnostic capabilities of the meter.

The three DPs are:
- the ‘traditional’ meter DP (DPt): P1-P2
- the ‘recovered’ DP (DPr): P3-P2
- the ‘permanent pressure loss’ DP (DPppl): P1-P3

Using the three DP readings, the pressure field through the meter is monitored and the three DPs are compared in multiple ways using other process conditions and meter geometry, providing powerful information on the meter’s performance using purely information which is already an integral part of the meter without the need for any inspection. Section 2.2 provides a full technical description.

SWINTON Technology has developed software including integration tools which communicates with an existing / third party supplied measurement system (or can be supplied as an integral part of a SWINTON Technology metering control system). The PROGNOSIS software runs the PROGNOSIS diagnostic calculations on live meter system inputs and displays and records the results (which can also be handed off to a third party system). The PROGNOSIS software provides the operator with a real time monitoring system as well as historical data views, real-time and historical trends, reporting, event logs and alarm management. Multiple meters can be monitored from the same software application. (The current software version can handle monitoring up to 50 flow meters at the same time. An extension to a larger number of DP-meters would be possible in consultation with ST.)

Condition based monitoring (CBM) system SWINTON 'PROGNOSIS'

Evaluated by SP Technical Research Institute of Sweden
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Report E 1956 X 14
Index classification 1.2

SP reference: 3P08719
Evaluation International Project No: 193

1. Introduction

This report describes an evaluation of the Condition Based Monitoring (CBM) system 'PROGNOSIS' from the vendor SWINTON (ST).
PROGNOSIS is a CBM system for any standard differential pressure (DP) flow meter design such as Orifice plate, Venturi meter (Venturi tubes and Venturi nozzles), Cone meter, flow nozzle, wedge meter, etc. and is a patented technology. The Intellectual Property (IP) rights to PROGNOSIS are held by DP Diagnostics LLC (DPD) and licensed to SWINTON Technology who have developed a software User Interface.

The overall objective of this evaluation report is to confirm that some specific data stated and published by the manufacturers are correct and valid. This, in combination with statistical testing and functional tests should be seen as a guide for the selection of devices for a specific application.

1.1. Equipment

The device undergoing test (device under test, DUT) was delivered to SP in May 2014. After acceptance of the offered test scheme in May 2014 the development of the test equipment started. The reported tests were performed starting at the beginning and during June 2014.

The main devices (measuring equipment) used for the sub-tests are listed in Table 1.

Table 1 – Overview of the used equipment for the evaluation tests

No.	Type	Serial no.	Comment
1	Device under test (DUT): SWINTON 'PROGNOSIS' - The differential pressure diagnostic system was installed with a 4" EMCO Orifice plate flow meter (Type MEF)	--- Serial no. Orifice flow meter: 2008664-1	The license to use PROGNOSIS for the testing was provided by ST and DPD. ST provided a PC which was installed with PROGNOSIS software and configured to communicate with SP's NI PXI DAQ system.
2	Test rig VM4 (DN 150) including 3.5 m^3 ball prover as (primary) reference standard	SP inv. number: 600385 (ball prover)	You can find more information in the BIPM key comparison database. (NMI service ID: SE26 and SE30)
3	RMV3 (Master meter) Micro Motion Mass Flow and Density Meter CMF 300	SP inv. number: 603186	Flow rate: 0 – 3000 kg/min Temperature: 0 – 200 °C
4	NI PXI DAQ-system	SP inv. number: 900020	NI PXIe-1062Q with three additional PXI modules: Multifunction DAQ (NI PXI-6238) Counter/Timer (NI PXI-6624) Temperature/Voltage (NI PXI-4351)
5	YOKOGAWA DP-transmitter EJA110EJHS5G-714EN	Serial no.: 91P329141	DPt DP-measurement range: 0-5 bar

6	YOKOGAWA DP-transmitter EJA110EJMS5G-714EN	Serial no.: 91NA15303	DPr DP-measurement range 0-1 bar
7	YOKOGAWA DP-transmitter EJA110EJHS5G-714EN	Serial no.: 91P329140	DPppl DP-measurement range: 0-5 bar
8	OLTRONIX power supply B200 (0-50 V, 0-2 A)	SP inv. number: 601665	Power supply for DPt
9	OLTRONIX power supply B200 (0-50 V, 0-2 A)	SP inv. number: 601666	Power supply for DPppl
10	MANSON power supply EP-613 (0-30 V, 0-2.5 A)	SP inv. number: ---	Power supply for DPr
11	NEWPORT current generator AE 560 (0-20 mA)	SP inv. number: 601423	Not calibrated (was only used for testing of the analogue inputs)

2. Tests

2.1. Instrument performance

The evaluation of the diagnostic system SWINTON 'PROGNOSIS' (DUT) was performed through a number of sub-tests, listed in Table 2. All errors and changes are indicated as falling within arbitrary bands and compared with the manufacturer's specification as follows:

√ Within the manufacturer's specification (or within test programme requirements)
X Outside the manufacturer's specification
■ No manufacturer's specification

Table 2 – Overview of the evaluation tests

No.	Test	Performance	Comment
1	Initial setup	√	
2	Incorrect set inline diameter D	√	
3	Incorrect set Orifice diameter d	√	
4	Incorrect set discharge coefficient (C_d)	√	
5	Blocked impulse (pressure) lines	√	
6	Leaking DP equalisation valve	√	
7	Incorrectly working DP transmitter	√	
8	Saturated DP Transmitter	√	
9	Drifting DP Transmitter	√	
10	DP Transmitter range incorrectly entered	√	
11	Influence of medium temperature	√	
12	Swirled inlet velocity profile	√	misinterpretation of the alarm
13	Asymmetric inlet velocity profile	√	
14	Multiphase flow (air bubbles)	√	
15	Backwards installed Orifice plate	√	
16	Orifice plate seated incorrectly in the orifice carrier	√	misinterpretation of the alarm

2.2. Mode of operation of the DUT (provided by SWINTON)

Figure 2 shows an orifice plate meter with instrumentation sketch and the (simplified) pressure fluctuation (or "pressure field") through the meter body. This pressure field is **wholly** dependent on the combination of DP geometry and the flow conditions. Therefore, the pressure field inherently contains a large amount of information regarding both the DP meter geometry and the actual flow conditions. Since the initial conception of the DP meter design, the very purpose of the primary element (e.g. orifice plate) has been to create this pressure field so that a difference in pressure within the field can be read and related to the flow rate. Hence, the pressure field has **always** been an integral part of the DP meter operating principle. However, traditionally, DP meters have not fully utilized this easily accessible and substantial pressure field information for flow metering or diagnostics purposes. Traditional DP meters only compare the difference in pressure at two set points within this pressure field. Therefore, traditionally DP meters are *needlessly* restricted in their capability compared to the substantial extra flow rate and diagnostic information that the pressure field as a whole has always offered. The DP meter diagnostic methods discussed here open up the potential of more closely monitoring the pressure field as a whole, thereby significantly increasing the capabilities of the DP meter on which the diagnostics are applied.

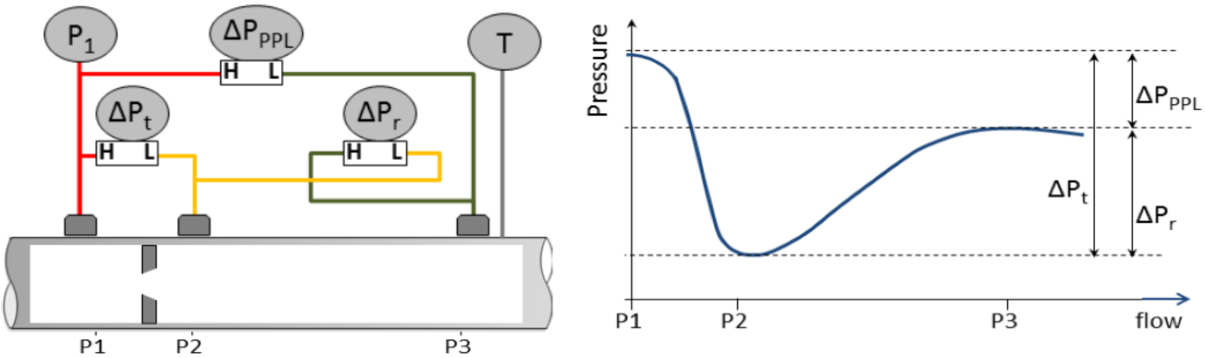

Figure 2 – Orifice meter with instrumentation sketch and pressure fluctuation graph.

Traditional DP meters read the inlet pressure (P_1), the downstream temperature (T) and the differential pressure (ΔP_t) between the inlet pressure tap (P1) and a pressure tap positioned in the vicinity of the point of low pressure (P2), created by the primary element. That is, traditionally DP meter technology only takes a single DP measurement from the pressure field. However, note that the DP meter run in Figure 2 has a third pressure tap (P3) further downstream of the primary element. This allows the measurement of two extra DPs. That is, it allows extra pressure field information to be read. The two extra DPs are the differential pressure between the downstream (P3) and the low (P2) pressure taps (or "recovered" DP, ΔP_r) and the differential pressure between the inlet (P1) and the downstream (P3) pressure taps (i.e. the permanent pressure loss, ΔP_{PPL}, sometimes called the "PPL" or "total head loss").

The sum of the recovered DP and the PPL **must** equal the traditional differential pressure (equation 1).

$$\Delta P_t = \Delta P_r + \Delta P_{PPL} \qquad (1)$$

Traditional Flow Equation: $\dot{m}_t = EA_tYC_d\sqrt{2\rho\Delta P_t}$ uncertainty ± x% (2)

Expansion Flow Equation: $\dot{m}_r = EA_tK_r\sqrt{2\rho\Delta P_r}$ uncertainty ± y% (3)

PPL Flow Equation: $\dot{m}_{ppl} = AK_{PPL}\sqrt{2\rho\Delta P_{PPL}}$ uncertainty ± z% (4)

The traditional orifice meter flow rate equation is shown here as equation 2. Traditionally, this is the only orifice meter flow rate calculation. However, with the additional downstream pressure tap three flow equations can be produced. That is, the recovered DP can be used to find the flow rate with an "expansion" flow equation (see equation 3) and the PPL can be used to find the flow rate with a "PPL" flow equation (see equation 4). Note $\dot{m}_t$, $\dot{m}_r$ and $\dot{m}_{PPL}$ represents the traditional, expansion and PPL mass flow rate equation predictions of the actual mass flow rate ($\dot{m}$) respectively. The symbol ρ represents the inlet fluid density. Symbols E, A and A_t represent the geometric constants of the velocity of approach, the inlet cross sectional area and the minimum (or "throat") cross sectional area through the meter respectively. The parameter Y is an expansion factor accounting for gas density fluctuation through the meter. (For liquids Y =1.) The terms C_d, K_r and K_{PPL} represent the discharge coefficient, the expansion coefficient and the PPL coefficient respectively.

These three flow coefficients can be found by calibrating the DP meter. Each can be set as constant values with set uncertainty ratings, or, may each be fitted to the Reynolds number, usually at a lower uncertainty rating. The Reynolds number is expressed as equation 5. Note that μ is the fluid viscosity and D is the inlet diameter. In the case of a flow coefficient being fitted to the Reynolds number, as the Reynolds number (Re) is flow rate dependent, each of the three flow rate predictions must be independently obtained by an iterative method. A detailed derivation of these three flow rate equations is given by Steven [1]. The orifice meter is a special case, as although it can be calibrated, an expression for the discharge coefficient can be found in ISO 5167-2 [2], and expressions for the expansion and PPL coefficients can be derived by other information contained within ISO 5167.

$$\mathrm{Re} = \frac{4\dot{m}}{\pi\mu D} \tag{5}$$

Every DP meter body is in effect three flow meters. As there are three flow rate equations predicting the same flow through the same meter body there is the potential to compare the flow rate predictions and hence have a diagnostic system. Naturally, all three flow rate equations have individual uncertainty ratings (say x%, y% & z% as shown in equations 2 through 4). Therefore, even if a DP meter is operating correctly, no two flow predictions would match *precisely*. However, a correctly operating DP meter should have no difference between any two flow rate predictions greater than the root sum square value of the two flow prediction uncertainties. Therefore, the maximum allowable difference between any two flow rate equations, i.e., $\phi\%$, $\xi\%$ & $\upsilon\%$ is shown in equation set 6a to 6c. If the percentage difference between any two flow rate predictions is less than the root sum square of those two flow rate prediction uncertainties, then no potential problem is found. If however, the percentage difference between any two flow rate equations is greater than the root sum square of those two flow rate prediction uncertainties, then this indicates a metering problem and the flow rate predictions should not be trusted. The three flow rate percentage differences are calculated by equations 7a to 7c:

Traditional & PPL Meters % allowable difference: $$\phi\% = \sqrt{(x\%)^2 + (z\%)^2} \tag{6a}$$

Traditional & Expansion Meters % allowable difference: $$\xi\% = \sqrt{(x\%)^2 + (y\%)^2} \tag{6b}$$

Expansion & PPL Meters % allowable difference: $$\upsilon\% = \sqrt{(y\%)^2 + (z\%)^2} \tag{6c}$$

Traditional to PPL Meter Comparison: $$\psi\% = \left\{\left(\dot{m}_{PPL} - \dot{m}_t\right)\Big/\dot{m}_t\right\}*100\% \tag{7a}$$

Traditional to Expansion Meter Comparison: $$\lambda\% = \left\{\left(\dot{m}_r - \dot{m}_t\right)\Big/\dot{m}_t\right\}*100\% \tag{7b}$$

PPL to Expansion Meter Comparison: $$\chi\% = \left\{\left(\dot{m}_r - \dot{m}_{PPL}\right)\Big/\dot{m}_{PPL}\right\}*100\% \tag{7c}$$

This diagnostic methodology uses the three individual DPs to independently predict the flow rate and then compares these results. With three flow rate predictions, there are three flow rate predictions pairs and therefore three flow rate diagnostic checks. In effect, the individual DPs are therefore being directly compared. However, it is possible to take a different diagnostic approach. The **P**ressure **L**oss **R**atio (or "PLR") is the ratio of the PPL to the traditional DP. Like the DP meter flow coefficients the PLR is a meter characteristic for all DP meters operating with single phase homogenous flow. It can be expressed as a constant value or related to the Reynolds number. We can rewrite Equation 1:

$$\frac{\Delta P_r}{\Delta P_t} + \frac{\Delta P_{PPL}}{\Delta P_t} = 1 \quad \text{--- (1a)} \qquad \text{where} \qquad \frac{\Delta P_{PPL}}{\Delta P_t} \text{ is the PLR.}$$

From equation 1a, if PLR is a set value (for any given Reynolds number) then both the Pressure Recovery Ratio or "PRR", (i.e. the ratio of the recovered DP to traditional DP) and the Recovered DP to PPL Ratio, or "RPR" must then also be set values. That is, all DP ratios available from the three DP pairs are constant values for any given DP meter geometry and Reynolds number. These three DP ratios can be found by calibrating the DP meter. Alternatively, for the particular case of an orifice meter not to be calibrated before use, an expression for the PLR can be found in ISO 5167-2 [2], and expressions for PRR and RPR can be derived by the information contained in ISO 5167-2. Thus we also have:

PPL to Traditional DP ratio (PLR):	$(\Delta P_{PPL}/\Delta P_t)_{expected}$,	uncertainty ± a%
Recovered to Traditional DP ratio (PRR):	$(\Delta P_r/\Delta P_t)_{expected}$,	uncertainty ± b%
Recovered to PPL DP ratio (RPR):	$(\Delta P_r/\Delta P_{PPL})_{expected}$,	uncertainty ± c%

Here then is another method of using the three DPs to check an orifice meters health. Actual DP ratios found in service can be compared to the fixed known correct values. Let us denote the percentage difference between the actual PLR and the known correct value as $\alpha\%$, the difference between the actual PRR and the known correct value as $\gamma\%$, and the difference between the actual RPR and the known correct value as $\eta\%$. These values are found by equations 8a to 8c.

$$\alpha\% = \{[PLR_{actual} - PLR_{expected} / PLR_{expected}]\} * 100\% \qquad (8a)$$

$$\gamma\% = \{[PRR_{actual} - PRR_{expected} / PRR_{expected}]\} * 100\% \qquad (8b)$$

$$\eta\% = \{[RPR_{actual} - RPR_{expected} / RPR_{expected}]\} * 100\% \qquad (8c)$$

If the percentage difference between the in-service and the known correct DP ratio is less than the stated uncertainty of that known DP ratio value, then no potential problem is found. If the percentage difference between the in-service and the known correct DP ratio is greater than the stated uncertainty of that known DP ratio value, then a potential problem is found and the flow rate predictions should not be trusted. With three DP ratios, there are three DP ratio diagnostic checks.

A seventh diagnostic method was added in 2012. Equation 1 holds true for all generic DP meters. Equation 1 is a consequence of the first law of thermodynamics and as such it cannot be violated, even if a DP meter has malfunctioned. Therefore, if all three DPs are directly read they can be checked against the infallibility of equation 1. As this equation must hold true, any result that suggests that it does not hold true is an absolute statement by the diagnostic system that there is an erroneous DP reading coming from the instrumentation (regardless of whether the meter body is serviceable or not). A DP meter reading all three DPs can infer the actual traditional DP (ΔP_t) by summing the read recovery DP (ΔP_r) and permanent pressure loss (ΔP_{PPL}). This gives an inferred traditional DP ($\Delta P_{t,\inf}$) that can be compared to the directly read traditional DP ($\Delta P_{t,read}$). Whereas theoretically these values are the same, due to the uncertainties of the three DP transmitters, even for correctly read DPs, they will be *slightly* different.

The percentage difference ($\delta\%$) can be calculated as seen in equation 9.

$$\delta\% = \{(\Delta P_{t,\inf} - \Delta P_{t,read}) / \Delta P_{t,read}\} * 100\% \quad (9)$$

The uncertainty rating of each DP reading will be known from the individual DP transmitter specifications. Therefore, it is possible to assign a maximum allowable percentage difference ($\theta\%$) between the directly read and inferred traditional DP values. However, it has been found in practice that as long as a reasonable population sample is taken (i.e. enough scans are averaged[1]) setting $\theta\% = 1\%$ is a reasonable practical value that covers a wide range of DPs measured. Therefore, if the percentage difference between the directly read and inferred traditional DP values ($\delta\%$) is less than the allowable percentage difference ($\theta\%$), then no potential problem is found. However, if the percentage difference between the directly read and inferred traditional DP values ($\delta\%$) is greater than the allowable percentage difference ($\theta\%$), then a problem with the DP measurements is confirmed and the flow rate predictions cannot be trusted.

Table 1 shows the seven possible situations that would signal a warning. Each of the seven diagnostic checks has ***normalized data***, i.e. each diagnostic parameter percentage difference output is divided by the allowable percentage difference for that parameter to produce the same warning threshold, i.e. >1. For convenience we use the following naming convention for the normalized data:

Normailised flow rate inter-comparisons: $x_1 = \psi\%/\phi\%$, $x_2 = \lambda\%/\xi\%$, $x_3 = \chi\%/\upsilon\%$

Notmalised DP ratio comparisons: $y_1 = \alpha\%/a\%$, $y_2 = \gamma\%/b\%$, $y_3 = \eta\%/c\%$

Normalised DP sum comparison: $x_4 = \delta\%/\theta\%$

Table 3 – The DP meter possible diagnostic results

DP Pair	No Warning	WARNING	No Warning	WARNING
ΔP_t & ΔP_{ppl}	$x_1 \leq 1$	$x_1 > 1$	$y_1 \leq 1$	$y_1 > 1$
ΔP_t & ΔP_r	$x_2 \leq 1$	$x_2 > 1$	$y_2 \leq 1$	$y_2 > 1$
ΔP_r & ΔP_{ppl}	$x_3 \leq 1$	$x_3 > 1$	$y_3 \leq 1$	$y_3 > 1$
$\Delta P_{t,read}$ & $\Delta P_{t,\inf}$	$x_4 \leq 1$	$x_4 > 1$	N/A	N/A

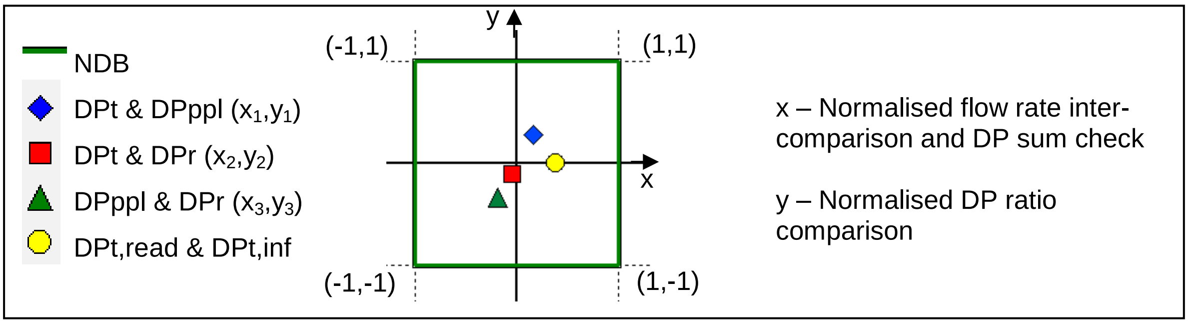

Figure 3 – Normalized diagnostic box (NDB) with diagnostic results, DP measurement check included.

[1] Most systems will read the DPs in sequence during a data sweep, i.e. the DPs are not typically read simultaneously and the three DP readings for a single diagnostic check will be out of synchronization. Even in "steady" flow each DP will have a finite standard deviation, i.e. it will fluctuate around its mean value. Therefore a representative population size has to be read to ensure that the three DPs used are the three average DP values and any effects of these natural DP fluctuations around their mean is smoothed out.

For practical real time (or historical auditing) use, a graphical representation of the diagnostics continually updated on a control room screen (while being archived) can be simple and effective. Any such graphical representation of diagnostic results should be immediately accessible and understandable to the average operator. Therefore, four points are plotted on a normalized graph (as shown in Figure 3). This graph's abscissa and ordinate (i.e. x & y axis) are number lines only, i.e. the axis have no units. On this graph a normalized diagnostic box (or "NDB") can be superimposed with corner co-ordinates: (1,1), (1,-1), (-1,-1) & (-1,1). On such a graph four meter diagnostic points can be plotted, i.e. (x_1,y_1), (x_2,y_2), (x_3,y_3) & $(x_4,0)$. Therefore, first, the three DPs have been split into three DP pairs and for each pair both the difference in the flow rate predictions and the difference in the actual to set known DP ratio are being compared to the maximum allowable differences. Secondly, the difference between the directly read and inferred traditional DP and is being compared to the maximum allowable difference. The abscissa is being used as a number line when the value $\delta\%/\theta\%$ (x_4) is being plotted (and the ordinate value is therefore zero by default). If the resulting diagnostic value falls within the range $-1 \le x_4 \le +1$ then the point $(x_4, 0)$ falls inside the NDB and no DP reading problem is noted. If the resulting diagnostic value falls out with the range $-1 \le x_4 \le +1$ then the point $(x_4, 0)$ falls outside the NDB and a DP reading problem is noted. If all points are within the NDB the meter operator sees no metering problem and the traditional meters flow rate prediction should be trusted. However, if one or more of the three points falls outside the NDB the meter operator has an indication that the meter is ***not*** operating correctly and that the meters traditional (or any) flow rate prediction cannot be trusted.

If the DPs are read correctly the diagnostics show $-1 \le x_4 \le +1$ regardless of whether there is any meter malfunction. A physical meter malfunction, where the DPs are still being correctly read, will be indicated by $-1 \le x_4 \le +1$ with one or more of the **other** diagnostic points outside the box. Such a plot indicates the problem is with the meter body and not the DP readings. However, if the DP readings are erroneous then the diagnostics will show that $-1 \le x_4 \le +1$ does not hold (i.e. this diagnostic point is outside the NDB) and therefore the DP readings **must** be erroneous, regardless of whether the meter has an additional physical meter malfunction or not. In this scenario the DP reading error/s could cause the other three diagnostic points to also be outside the NDB. However, from the fact that the $(x_4, 0)$ falls outside the NDB the operator categorically knows the DP readings are the source (or one of the sources) of the meter malfunction. Once, the DP reading problem is fixed, if one or more of the other points are still out the box then the operator knows the meter body had also malfunctioned. Therefore, such a plot as Figure 3 allows the meter operator to not only see a problem but be able to distinguish the problem between a secondary DP instrumentation problem and a primary meter body based physical problem.

The further from the NDB the points are, the more potential for significant meter error there is. Note that in this random theoretical example shown in Figure 3 all points are within the NDB indicating the meter is operating within the limits of normality, i.e. no metering problem is noted.

For details on how the 'Compensation Factor(s)' e.g., 'Z Factor' technique works see Skelton et al. [4])

2.3. Construction

SWINTON Technology (ST) provided software installed on a laptop which was pre-configured with a Modbus link and data map in order to acquire meter data in real-time from the NI PXI DAQ system, perform diagnostic calculations, display the results at the time of testing and archive all results for future playback and analysis.

2.4. Installation and Commissioning

SP installed the PROGNOSIS PC (provided by ST) in the lab and connected it to the NI PXI DAQ system to verify communications prior to testing.

SWINTON have pre-configured a Modbus map and provided instructions for installing and commissioning of the CBM. The ModBus communication link has been configured with PROGNOSIS acting as Master (function code 3 'Read Holding Registers') on the link.

Via a single Ethernet communication link using ModBus (TCP/IP) protocol the following settings were present:

Mode:	MODBUS_TCP
IP Address:	10.10.10.2
Gateway:	255.0.0.0
Port:	5001

The communications settings are configurable by the end user and if the 'standard' offering does not cover the user's requirements, ST is able to configure bespoke communications links using other industry standard protocol.

2.5. Comments on documentation

A comprehensible instruction manual ('PROGNOSIS USER MANUAL') was supplied with the CBM system. This implies a special version for the evaluation tests with 47 pages.

2.6. Manufacturer's comments

The following comments received from the Manufacturer have been reproduced verbatim. Any references to page numbers have been adjusted in line with this final report where necessary.

General Comments / Relevant Information

Swinton Technology (ST) considers the testing of Prognosis at SP facilities on behalf of Evaluation International to be successful, in that Prognosis performed as expected in response to the tests performed.

ST Provided a (off the shelf) Dell Latitude 3540 BBTX laptop PC installed with Prognosis software which was configured (using standard editor tools available to the end user) to communicate with SP's SCADA system and licensed to monitor 1 meter. No other hardware or instrumentation was provided by ST. The application of Prognosis requires the use of a third tapping point downstream of the meter and three DPs to be measured, as illustrated in the diagram in Figure 1 and Figure 2 of the report. All instrumentation, Orifice meter and reference meters were supplied or sourced by SP.

Important general point: Prognosis looks for actual flow rate prediction errors, not non-ISO compliant meters which is a subtle but important difference. Sometimes meter systems which are not strictly ISO compliant will still produce a flow rate prediction error which is within allowable uncertainties, this was illustrated by Test 5 (blocked pressure port) in cases where the pressure had not changed significantly enough since the port was blocked to affect the flow rate prediction and by Test 13 ('crescent moon plate' 12 D upstream of the Orifice plate) where the disturbance upstream had no significant influence on the flow pattern at the inlet.

The Prognosis User Interface can monitor many meters at once and has the following standard displays, each selectable via corresponding display window tabs across the top of the screen:

Tab	Description
Home	System information including license details and running applications.
Meters 1-20	Miniature NDB for each configured meter.
Prognosis History	Play back of archived/historical data for the selected meter.
Prognosis Mimic	Simplified mimic of selected meter including live data.
Current Data	Live data and NDB for the selected meter. Access to meter settings pages from the 'Current In-Use Data' box.
Alarms	Full list of alarms (filterable).
Events	Full list of events (filterable).
Reports	List of reports automatically generated by Prognosis.
Trending	Historical data trends for the selected meter.
Communications	Communication diagnostic statistics.

The 'Current Data' display is selected by default.

A separate "Standard Prognosis Displays" document has been provided which includes extracts from the more detailed User Manual.

Comments Relating to Specific Report Sections

Comments against tests 12 and 16 (summary table on Page 2): In these two cases, Prognosis correctly detected that an issue was present. The comment refers to the text which is displayed on the User Interface which is a guide or suggestion as to the actual issue which would cause such a diagnostic response (i.e., a particular 'pattern'). ST does not claim that the possible issues listed will always include the actual issue (the text begins “possible issues include…”) and this is stated in the Prognosis License Agreement. However, the possible causes presented to the end user are continually being reviewed and will become more accurate with further testing of particular issues. In the next version of the Prognosis software, the particular issues of ‘inlet swirl’ and ‘orifice plate incorrectly seated’ will be included in the Prognosis literature as possible causes of alarm.

Note on Isentropic Exponent and Expansibility Factor (footnote 4 on page 24, section 4.1): The next version of the Prognosis software has additional checks in the calculation blocks which will result in the Isentropic Exponent only being used when necessary and any division by zero being avoided. The next version of software will also ask the end user to select whether the fluid is gas or liquid and if liquid, will automatically set the expansibility term to 1.

Note on screen shots and addition to text on page 25, section 4.1: The Prognosis User Interface ‘Current Data’ screen displays the label “Compensation Factors: On”, this relates entirely to the very small compensation applied due to the Corner tapping arrangement producing a slightly higher Pressure Loss Ratio than is predicted by the ISO5167 [2] “Urner” equation which is used by Prognosis in order to provide a baseline for Orifice meters which are not calibrated (as is typical in industry). The small ‘Z’ factor applied in this case is used to modify 5 of the 6 expected meter characteristics (all but the discharge coefficient) to allow for the additional head loss. In this case Z = 0.007 means that the actual Permanent Pressure Loss and the expected (“Urner” predicted) Permanent Pressure Loss disagree by approximately 0.7% of the ‘traditional’ meter DP.

Comment on test 8 a), page 58: This test shows an important point. The most direct way of checking the DP integrities is by the DP sum (yellow point). But the other points are also sensitive to a DP reading error. Here we see the red point y-axis result (i.e. the PRR) is actually more sensitive to the wrong DPr than the DP check. It sees the problem at a smaller error than the DP sum integrity check.

Comment on Test 11, page 65: There is no claim that Prognosis is sensitive to changes in temperature as this test proved.

Addition to ‘Comments concerning the tests’ (Section 4.17 a), page 85): When the Prognosis response is unsteady, this is a result of the DP inputs (being measured by the orifice meter's DP transmitters) being unsteady. The Prognosis software provides two methods of avoiding false alarms due to naturally unsteady flow; the first is to average the DP inputs over a specific period of time (the end user enters the averaging period in seconds), the second is to introduce an ‘alarm delay’ setting so that an alarm is only raised in the system when a specific diagnostic response has been present for ‘n’ seconds or longer (‘n’ is user enterable). Both methods may be used together.

3. Measurement set-up

3.1. Test facility

SP as National Metrology Institute (NMI) holds the national laboratories for volume, flow and temperature and has a variety of flow calibration facilities using water between 15 ˚C and 90 ˚C and flow rates up to 200 L/s (12000 L/min; 720 m^3/h). SP has organized and participated in many European inter-comparisons and proven its capability.

The measurements with the ANSI 4" (inner diameter 102.26 mm) Orifice plate were performed at the primary flow rig VM4, as shown in figure 2. The primary flow rig with the NMI service identifiers SE26 and SE30 has an extended measurement uncertainty of U(k=2) = 0.06 % (10 – 30 ˚C) and U(k=2) = 0.08 % (30 – 90 ˚C) (approved on 19 December 2012) according to BIPM CMC tables.

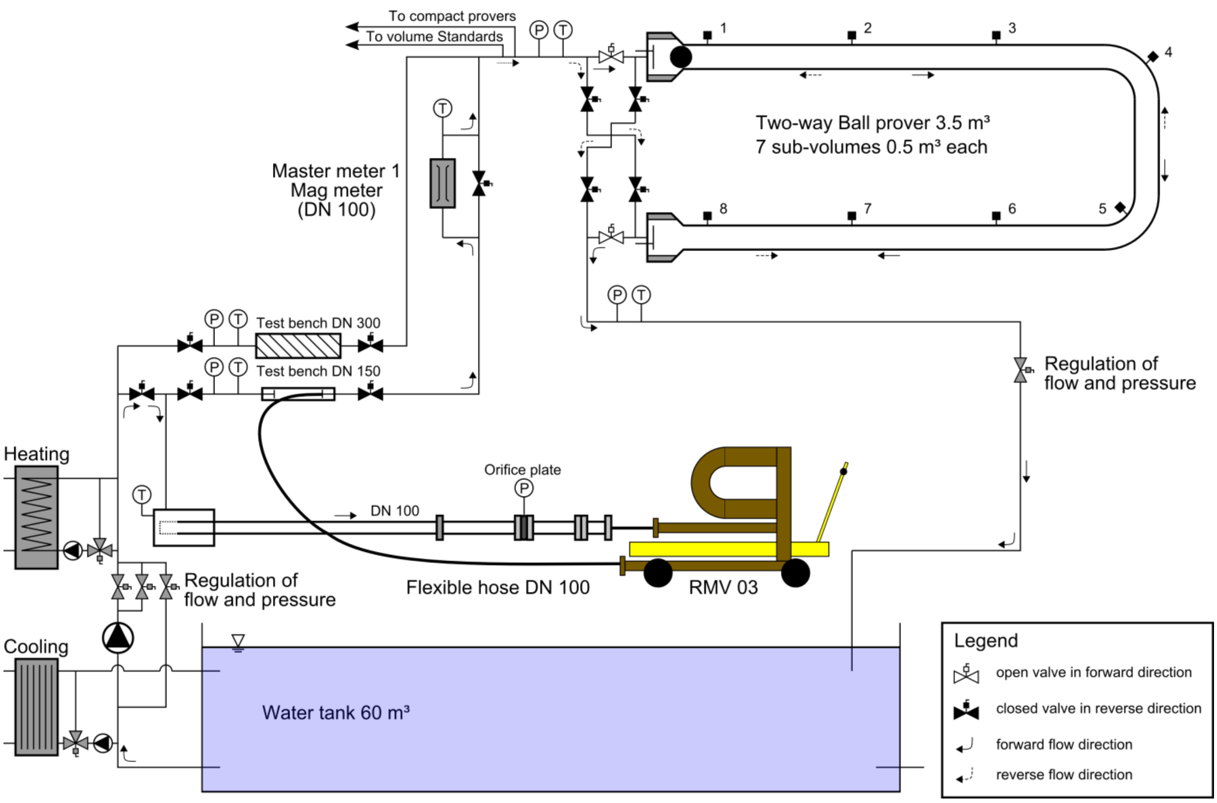

Figure 4 – Simplified flow scheme of the calibration test rigs VM3 (test bench DN 300) and VM4 (test bench DN 150) at SP

A total of two compact piston provers with 20 L / 60 L and 250 L for the lower flow rates and a ball prover with 0.5 m^3 to 3.5 m^3 for the higher flow rates are available as primary standards.
VM4 offers the additional possibility to calibrate - in comparison to other primary standards - more precisely two volume standards of 1.0 m^3 and 3.5 m^3.

The orifice meter performance was subsequently measured with a series with at least five repetitions per series in comparison with the ball prover (primary standard).

For the measurements an electromagnetic flow meter (mag meter) and a Coriolis mass flow meter (CMF) were calibrated as secondary standards at the same time with the ball prover at the desired test points. Afterwards the evaluation tests with the Orifice plate flow meter were performed in comparison with the calibrated mag meter and CMF. The differential pressure of the Orifice plate was measured with a differential pressure transmitter (DP-transmitter). Before each calibration a zero-point measurement of the DP-transmitter was performed.

3.2. Installation

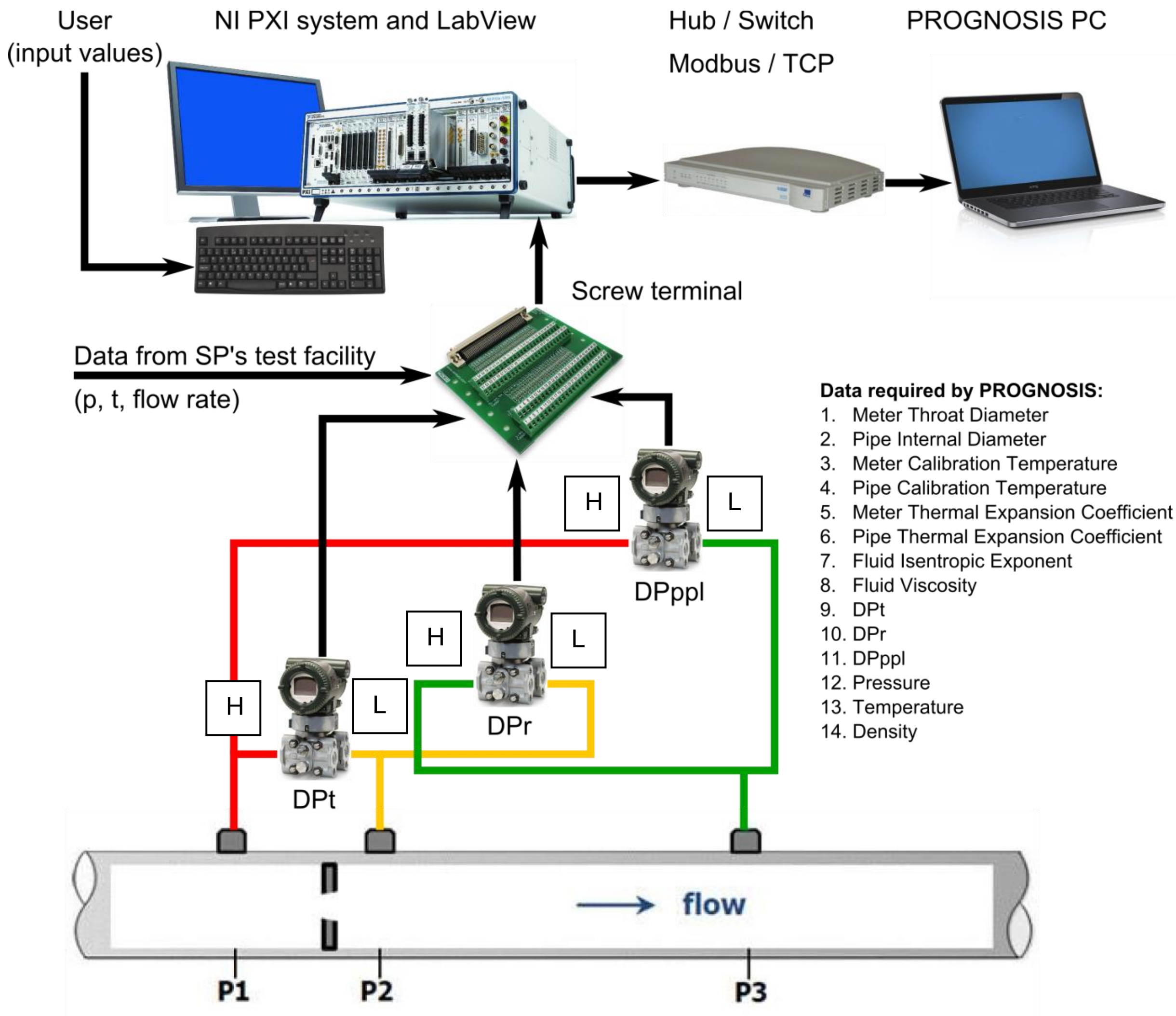

Figure 5 – Overview of the

DP-transmitter (Differential pressure transmitter)

For the differential pressure measurements DP-transmitter from YOKOGAWA were used:

- DPt (‘traditional DP’ P1-P2):
  YOKOGAWA DP-transmitter EJA110EJHS5G-714EN,
  measurement range: 0-5 bar

- DPr (‘recovered DP’ P3-P2):
  YOKOGAWA DP-transmitter EJA110EJMS5G-714EN,
  measurement range 0-1 bar

- DPppl (‘permanent pressure loss DP’ P1-P3):
  YOKOGAWA DP-transmitter EJA110EJHS5G-714EN,
  measurement range: 0-5 bar

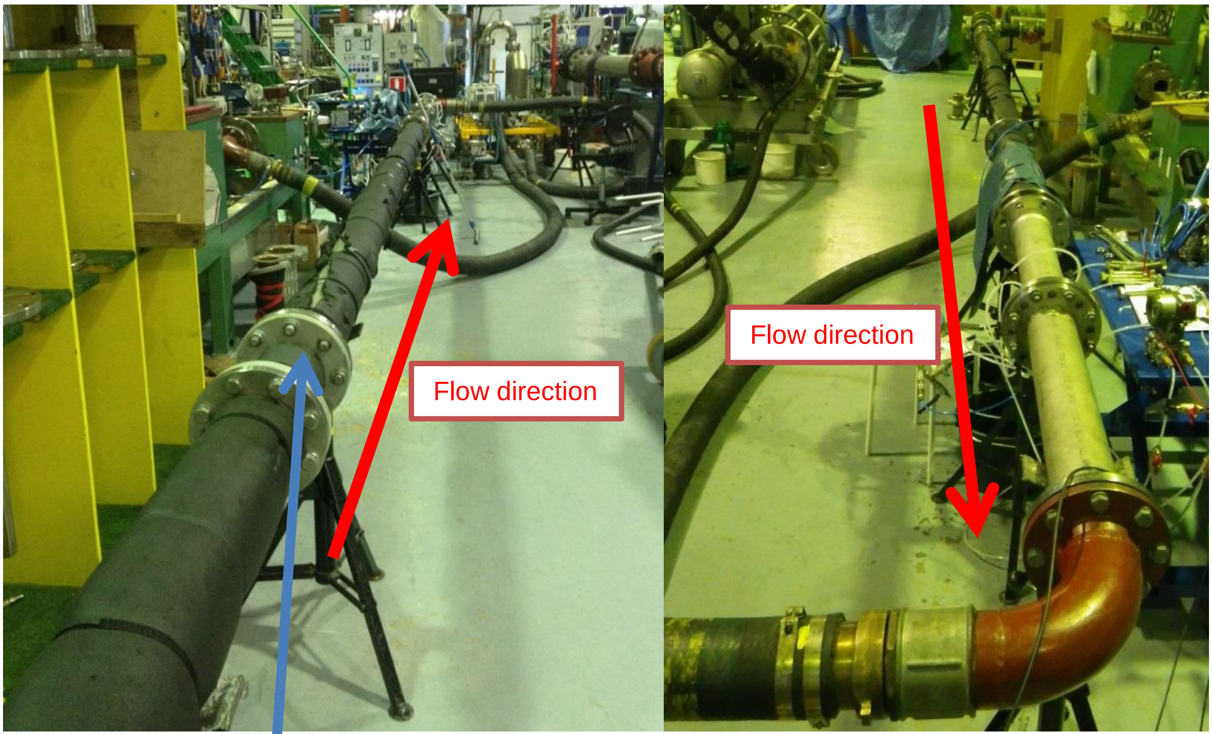

Figure 6 – Overview of the measurement section

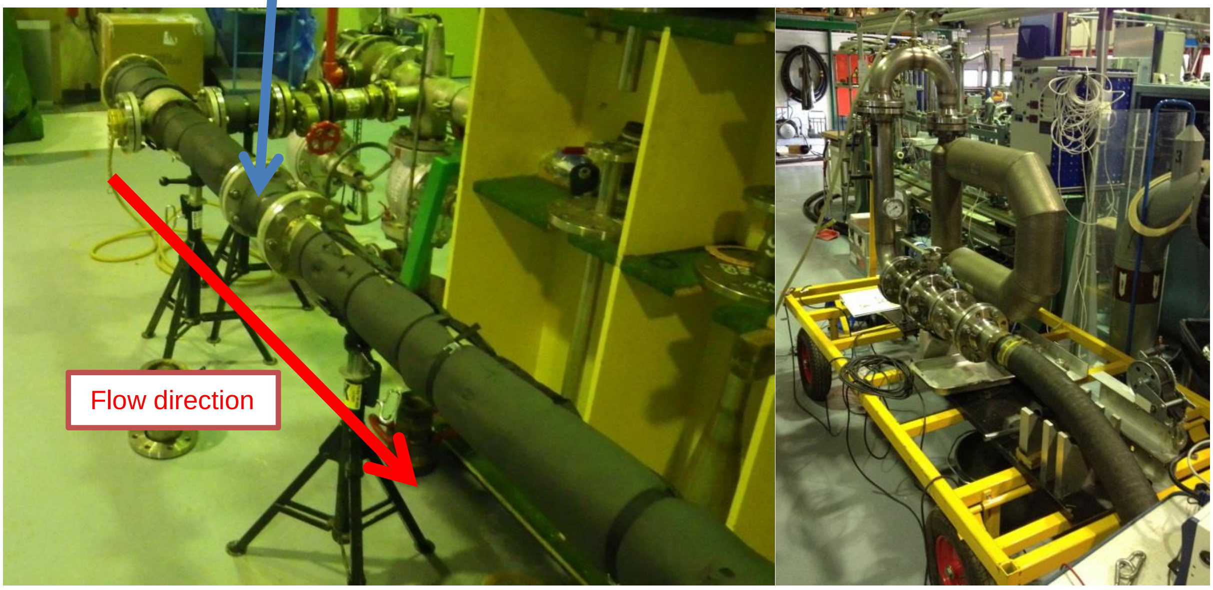

Figure 7 – Left: Start of the measurement section (inlet situation); Right: Reference meter RMV3

Measurement configuration (see also Figure 4):

50 D straight pipe inlet section DN 100, meter package (12.5 D inlet section, Orifice plate flow meter, 7.5 D outlet section), 50 D flexible rubber hose DN 100, RMV3, 80 D flexible rubber hose DN 100 connected to the end of the measurement section of VM4 with a diffuser DN 100 / DN 150.

RMV3 (Swedish: 'Referensmätarvagn nr. 3') is a so-called 'master meter trolley' and consists of a Micro Motion® ELITE® Mass Flow and Density Meter CMF 300 (Coriolis mass flow meter). It allows measuring the flow rate, density and temperature and output of the values as pulse or current signal.

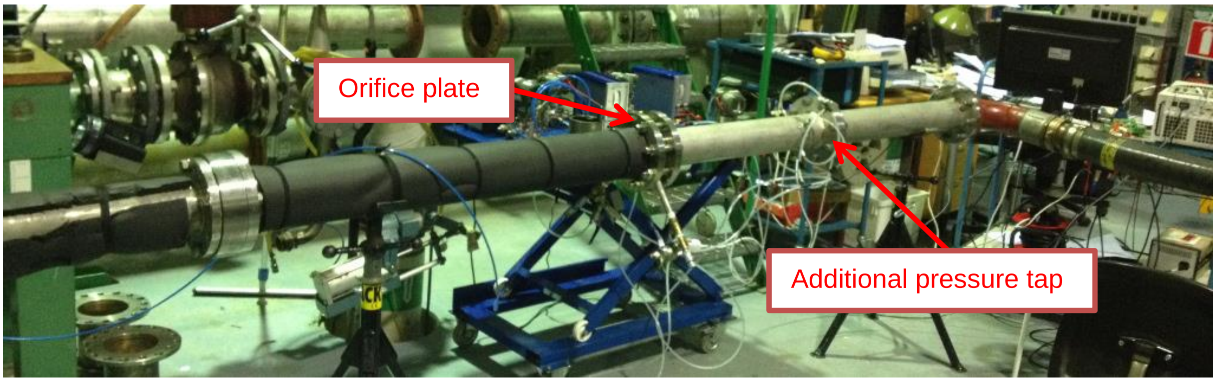

Figure 8 – Installation situation of the Orifice plate and the additional pressure tap (about 6 D downstream)

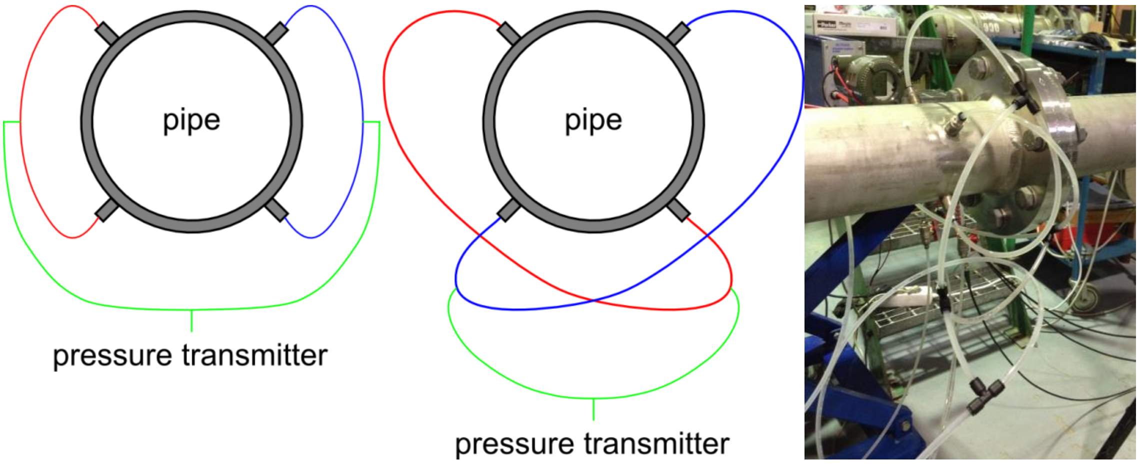

Figure 9 – Left and middle: Recommended configuration (best practise guide) for impulse lines of Differential Pressure (DP) meters; Right: Used configuration (see also picture in the middle)

The additional pressure taps were installed about 6 D downstream from the Orifice plate flow meter on the outlet pipe of the meter package. In order to have a good averaging over the whole cross-section an arrangement represented in Figure 9 was used.

NI PXI system (National Instruments – **P**CI e**X**tensions for **I**nstrumentation)

For the investigations a NI PXIe-1062Q with 3 additional PXI modules [Multifunction DAQ (NI PXI-6238) and Counter/Timer (NI PXI-6624) and Temperature/Voltage (NI PXI-4351)] was available.

Since all signals were available as current signals (4-20 mA) only the DAQ NI PXI-6238 with the additional screw terminal NI CB-37F-HVD (see Figure 10) was used.

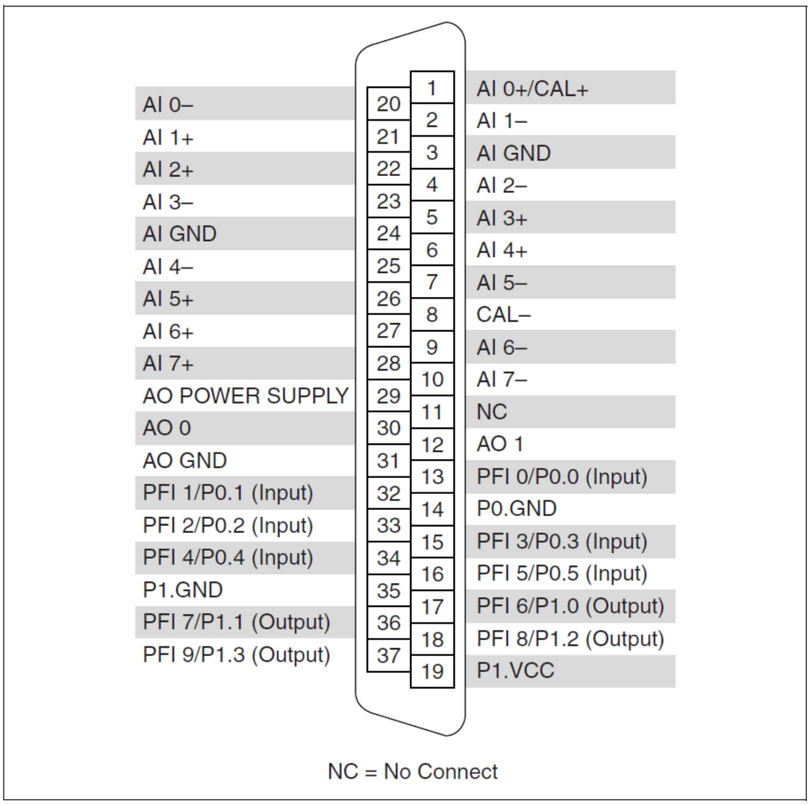

Figure 10 – Pin assignment of the DAQ screw terminal

ModBus/TCP IP[2]

TCP means Transmission Control Protocol and IP stands for Internet Protocol. These protocols are used together and are the transport protocol for the internet. When ModBus information is sent using these protocols, the data is passed to TCP where additional information is attached and given to IP. IP then places the data in a packet (or datagram) and transmits it.

TCP must establish a connection before transferring data, since it is a connection-based protocol. The Master (or Client in Modbus TCP) establishes a connection with the Slave (or Server). The Server waits for an incoming connection from the Client. Once a connection is established, the Server then responds to the queries from the Client until the client closes the connection.

In this case the SWINTON PROGNOSIS CBM system worked as *Client* (or Master) (function code 3) and the NI PXI system (see Figure 5) worked as *Server* (or Slave). In order to provide the data for the SWINTON PROGNOSIS CBM system a computer program (LabView) was written before the actual tests.

[2] http://www.simplymodbus.ca

3.3. LabView program

Figure 11 – Program interface (user interface) of the LabView program

The basis of the examination was a (self-written) LabView program which provides the required data via ModBus/TCP for the SWINTON PROGNOSIS CBM system.

The program interface of the LabView program (see Figure 11) consists of three parts: on the left side ('input data') of an input window, where the user has the possibility to enter data.
In this case the first 7 (fixed values) of in total 14 required values by PROGNOSIS (see Figure 5):

1.) **Orifice meter throat diameter**
2.) **Pipe internal diameter**
3.) **Meter calibration temperature**
4.) **Pipe calibration temperature**
5.) **Meter thermal expansion coefficient**
6.) **Pipe thermal expansion coefficient**
7.) **Fluid isentropic coefficient**[3]

In the middle part of the program ('live data') the user has the possibility to see a chart of current values recorded by the analogue inputs of the NI PXI system.
The setting of the analogue input can be changed in the lower part of the window. The default values were e.g. a 'sample rate' of 1000 Hz and a 'samples to read'-value of 1000.

By using the analogue inputs further input data can be provided for the PROGNOSIS system such as:

9.) **Differential pressure DPt**
10.) **Differential pressure DPr**
11.) **Differential pressure DPppl**
12.) **Line pressure**
13.) **Fluid temperature**

An overview of the collected data is shown in Table 4.

The last two values [**8.) Dynamic fluid viscosity** and **14.) Fluid density**] were calculated by means of the fluid temperature (see chapters 3.3.1 and 3.3.2).

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[3] This input is not required for liquid applications

Table 4 – Overview of the used analogue inputs

Analogue Input	Description
AI0	Differential pressure DPt
AI1	Differential pressure DPr
AI2	Differential pressure DPppl
AI3	Line pressure
AI4	Temperature (RMV3)
AI5	Flow rate (Coriolis meter, RMV3)

As already stated, all input signal were available as current signals with (0)4-20 mA.

The analogue outputs (AI0, AI1 and AI2) from the three DP-Transmitter (DPt, DPr, DPppl) were directly provided (see
Figure 12). For the power supply adjustable (0-30 VDC) laboratory power supplies were used.

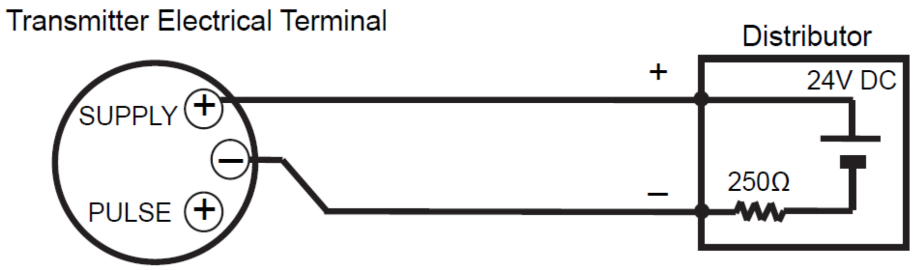


Figure 12 – Connection example for the analogue output of a YOKOGAWA DP-transmitter

The pressure sensor in the measurement section (AI3) also had a current signal output.
For the temperature measurement the temperature sensor signal output as current signal 0(4)-20 mA of RMV3 (AI4) was used.

In order to compare the flow rates in real-time the flow rate signal as current signal (0)4-20 mA of RMV3 (AI5) was used. This flow rate signal and the flow rate pulse signal were calibrated (see chapter 4.1 and 4.11) before the relevant tests.

An aside: The flow rate signal of RMV3 (AI5) was not required by PROGNOSIS but was used as 'display value' (see also Figure 11 'Current flow rate') in order to compare the actual flow rate (RMV3) with the flow rate indicated by the Orifice plate flow meter.
On the other hand it is very useful to compare the orifice meter and reference meter flow rate predictions as this allows the actual bias induced by the deliberate orifice meter malfunction to be known.

3.3.1.Calculation of the fluid density by means of the fluid temperature

For the calculation of the density by means of the fluid temperature (at a constant pressure of 0.1 MPa) a formula given by *Bettin* and *Spieweck* [5] was used:

$$\rho_w = \frac{\sum_{n=0}^{5} a_n \cdot t^n}{1 + b \cdot t}$$

Table 5 – Coefficients for the calculation of density according to *Bettin* and *Spieweck*.

n	a_n	b
0	$9.9983952 \cdot 10^{2}$	$1.6887236 \cdot 10^{-2}$
1	$1.6952577 \cdot 10^{1}$	
2	$-7.9905127 \cdot 10^{-3}$	
3	$-4.6241757 \cdot 10^{-5}$	
4	$1.0584601 \cdot 10^{-7}$	
5	$-2.8103006 \cdot 10^{-10}$	

The formula provides a simple dependence of the density on the temperature but provides in contrast to e.g. the IAPWS formula no dependence on the line pressure. An implementation of the IAPWS formula (pressure dependence) would be possible at any time, but was not needed for the relative low pressures in this case.

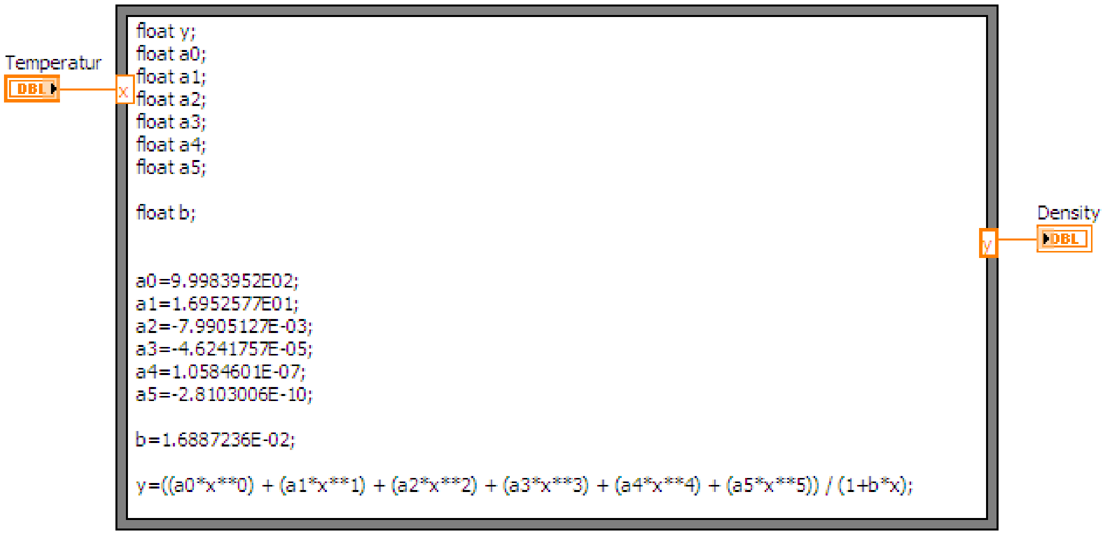


Figure 13 – Calculation of the density by means of the fluid temperature in LabView

3.3.2.Calculation of the dynamic viscosity by means of the fluid temperature

For the calculation of the (dimensionless) dynamic viscosity by means of the fluid temperature (at a constant pressure of 0.1 MPa) a formula given by Huber et al. [6] was used:

$$\bar{\mu} = \sum_{i=1}^{4} a_i (\tilde{T})^{b_i}$$

where $\tilde{T} = T/(300\ K)$ and a_i and b_i are coefficients and exponents given in Table 8.

The equation is recommended for use in the temperature range of $253.15\ K \leq T \leq 383.15\ K$ and should not be extrapolated outside these limits.

Table 6 – Coefficients for the calculation of density according to *Huber et. al.*

i	a_i	b_i
1	280.68	-1.9
2	511.45	-7.7
3	61.131	-19.6
4	0.45903	-40.0

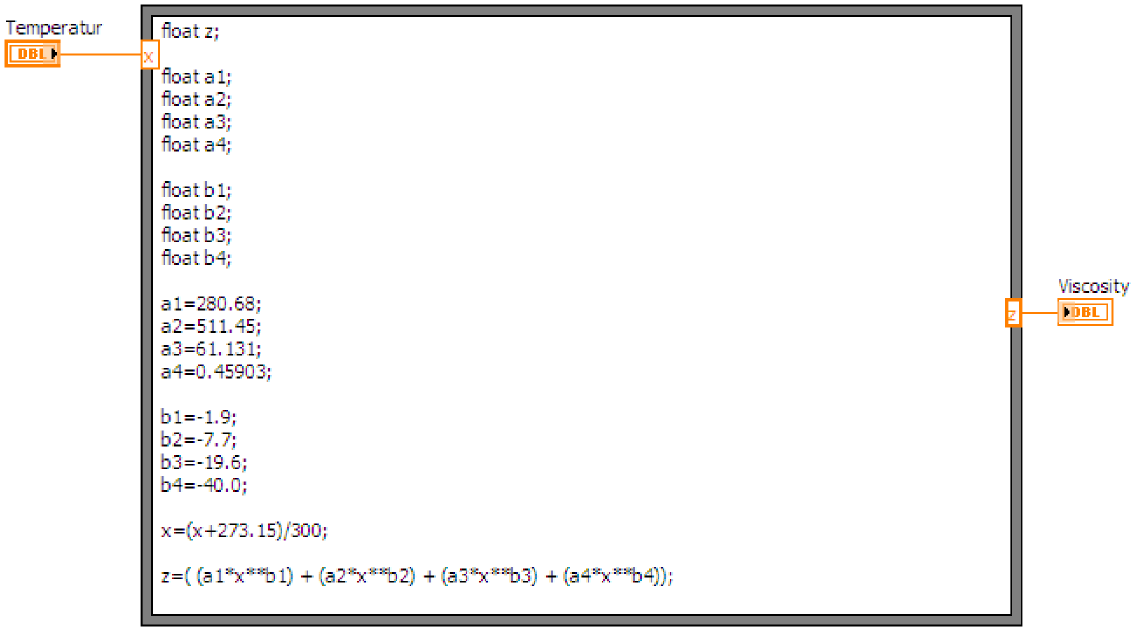


Figure 14 – Calculation of the viscosity by means of the fluid temperature in LabView

As a side note: The kinematic viscosity (*v*) is the ratio of the dynamic viscosity μ to the density ρ of the fluid.

3.4. Transmission of the data from the LabView program to SWINTON PROGNOSIS

On the right side of the program interface (see Figure 11 ‘output data’) the current output data (updating every second) can be seen. Not all the data corresponds with the data required by PROGNOSIS.

Some values need to be converted, e.g. the values form the analogue inputs have to be converted from current signal [mA] to a pressure value [mbar]:

DPt and DPr (4...20 mA corresponds to 0…5 bar):

$$value[bar] = 0.3125 \cdot value[mA] - 1.25$$

DPppl (4...20 mA corresponds to 0…1 bar):

$$value[bar] = 0.0625 \cdot value[mA] - 0.25$$

Line Pressure (4...20 mA corresponds to 0…16 bar):

$$value[bar] = -401.416 + 100.56 \cdot value[mA] - 0.0145393 \cdot value[mA]^2$$

Temperature RMV3 (4...20 mA corresponds to 0…200 ˚C):

$$value[°C] = 12.5 \cdot value[mA] - 50$$

Flow rate RMV3 Coriolis meter, CMF (4...20 mA corresponds to 0…3000 kg/min):

$$value\left[\frac{kg}{min}\right] = 187.5 \cdot value[mA] - 750$$

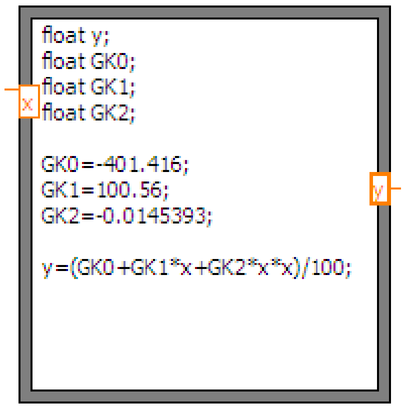


Figure 15 – Conversation of the line pressure [bar] from the current output [mA] of the calibrated pressure sensor in LabView

All values have a 'double-precision, floating-point' data type and have to be converted to 'word signed integer' in order to meet the requirements for the data transmission via ModBus.

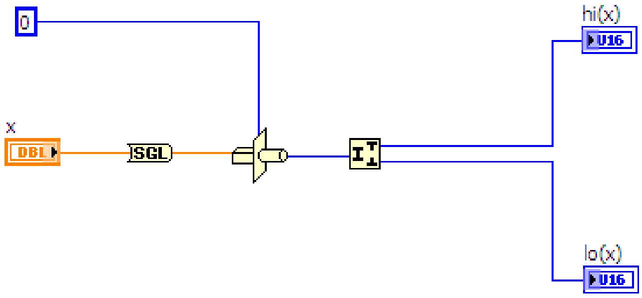


Figure 16 – Conversation of a 'double precision' value to a 'word signed integer' for ModBus in LabView

Figure 16 shows a simple example for the conversation of a value present as 'double precision, floating point' data type to a data type of 'word signed integer' with prior conversation of the value in a data type of 'single-precision, floating-point' using LabView.

As an example the value for the Orifice diameter '51.13' (data type 'double precision, floating point') would be converted to '16972' (number before the comma) and '34079' (number after the comma) (both data types are 'word signed integer').

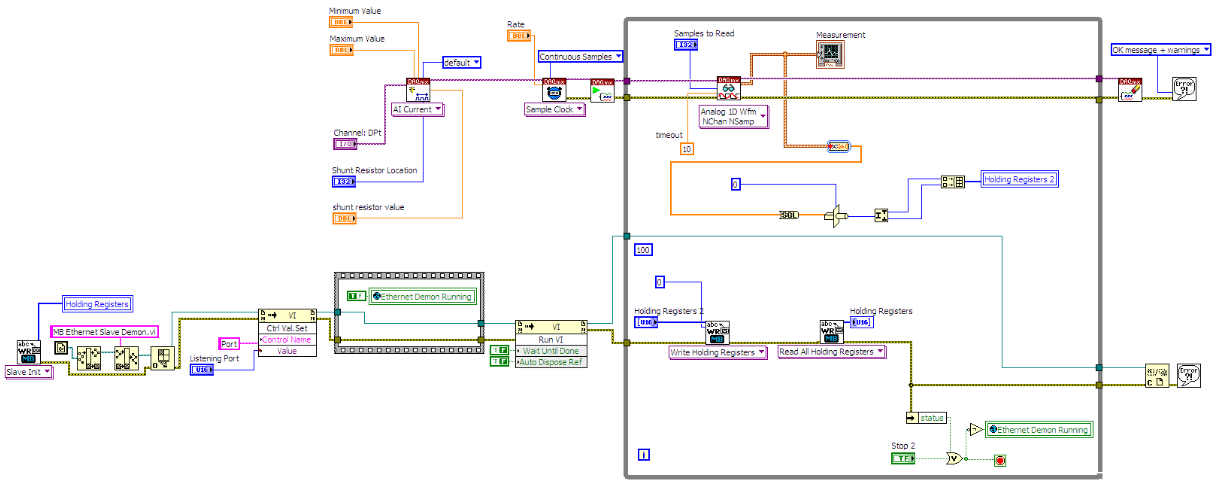


Figure 17 – Simplified LabView program as an example for ModBus communication

Figure 17 shows a simplified program (in order to understand the operation of the used LabView program) which reads out an analogue channel (current signal), provides the data in a chart, converts the data at the same time from the data type 'double precision, floating point' to two values with the data type 'word signed integer' and provides the data in two so-called 'holding registers' for the ModBus TCP communication.

The used LabView program works quite similar but reads-out at the same time six analogue channels (see Table 4) and provides 14 values in total in 28 'holding registers' – that means values are written into 28 register addresses (two addresses for each value) – see also Figure 11.

3.5. Measurement plan

The presentation of the results is carried out by utilizing the Reynolds number. One advantage of using the Reynolds number is that the solution for any possible measurement condition can be found from a few, exemplary measurements if the dimensionless parameters are the same as in these tests. Besides that, the use of the dimensionless Reynolds number leads to a reduction of the complexity of the intended mathematical temperature model. The Reynolds number is described in the general form as:

$$Re = \frac{w_{vol} \cdot d_h}{\nu} = \frac{w_{vol} \cdot D}{\nu} \quad \text{with:} \quad d_h = \frac{4 \cdot A}{P}$$

In this equation w_{vol} is the volumetric velocity, v the kinematic viscosity and D the pipe inner diameter. Furthermore the hydraulic diameter d_h represents the ratio between cross-sectional area A and perimeter P of the pipe or measuring section.

The equation also shows that different combinations of the flow rate and the viscosity (indirectly fluid temperature) result in the same Reynolds number. In the best case the same Reynolds number will lead to the same discharge coefficient. This was especially shown for Orifice plate flow meters by *Stolz* (Stolz-equation before 1993) and *Reader-Harris* and *Gallagher* (RHG-equation) as part of the standard ISO 5167 [2]. In this case different combinations of flow rates and fluid temperatures were investigated and have legitimated these expectations.

Table 7 – Fixed test plan including the resulting flow rates for the different Reynolds numbers

			Reynolds number									
			100000		200000		250000		300000		400000	
Temp.	Visc.	Dens.	Vol. flow rate	Mass flow rate	Vol. flow rate	Mass flow rate	Vol. flow rate	Mass flow rate	Vol. flow rate	Mass flow rate	Vol. flow rate	Mass flow rate
˚C	mPa·s	kg/m^3	l/min	kg/h	l/min	kg/h	l/min	kg/h	l/min	kg/h	l/min	kg/h
20	1.002	998.21	482.66	481.80	965.33	963.59	1206.66	1204.49	1447.99	1445.39	1930.65	1927.19
30	0.797	995.65	384.23	382.56	768.46	765.12	960.58	956.40	1152.70	1147.68	1536.93	1530.24
40	0.653	992.22	314.66	312.22	629.33	624.43	786.66	780.54	943.99	936.65	1258.65	1248.87
50	0.547	988.05	263.52	260.37	527.04	520.74	658.81	650.93	790.57	781.12	1054.09	1041.49
60	0.466	983.21	224.75	220.98	449.51	441.96	561.89	552.45	674.26	662.94	899.02	883.92
70	0.404	977.78	194.64	190.31	389.27	380.62	486.59	475.78	583.91	570.93	778.54	761.24

For this reason a measurement program based on fixed Reynolds numbers for different temperatures (see Table 7) was selected for the tests.

4. Test results

4.1. Test 1 – Initial setup

Hardware and measurement set-up including basic measurements and 5-point calibration of the Orifice plate flow meter (medium temperature 20 ℃ and 5 repetitions at each point) as reference case

Objective – to build-up the test rig, experience in handling
Criteria – Test rig needs to be operational, conspicuities must be reported.

Preparation of the Orifice plate

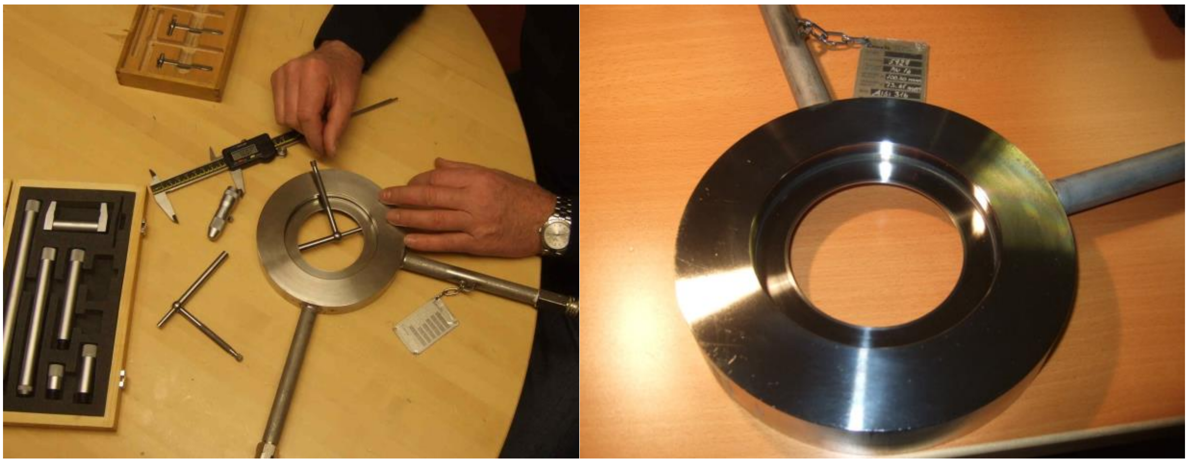
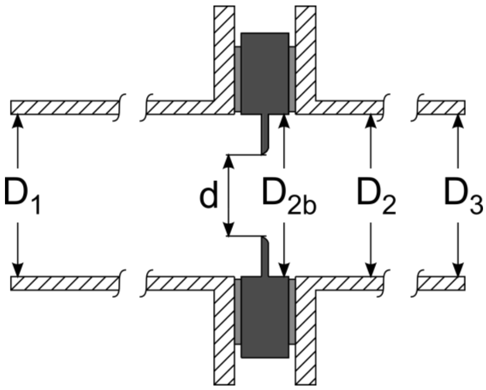


Figure 18 – Preparation of the Orifice plate flow meter and measurement of the Orifice plate flow meter geometry



	Nominal	Measured
d	51.13	51.13
D_1	102.26	101.84
D_2	102.26	102.26
D_{2b}	102.26	103.49
D_3	102.26	102.28
β	0.500	0.494

Figure 19 – Nominal and measured diameters (mm) of the Orifice plate (with a sharp edge, an annular chamber and corner tappings) and the resulting value of the diameter ratio β

During the tests the nominal values of the Orifice plate flow meter were used as default values.

Preparation of PROGNOSIS

The PROGNOSIS software was provided on a laptop, configured to acquire the following input data from SP's NI PXI system:

Table 8 – Input data for the SWINTON PROGNOSIS CBM system (source: SWINTON)

Input Description	Value	Units
Meter Throat Diameter	51.13 (Keypad in SP system)	mm
Pipe Internal Diameter	102.26 (Keypad in SP system)	mm
Meter Calibration Temperature	20.01 (Keypad in SP system)	degC
Pipe Calibration Temperature	20.01 (Keypad in SP system)	degC
Meter Thermal Expansion Coefficient	0.000016 (Keypad in SP system)	mm/mm/degC
Pipe Thermal Expansion Coefficient	0.000016 (Keypad in SP system)	mm/mm/degC
Fluid Isentropic Exponent	Not applicable as only used to calculate expansibility which is 1 for liquid. Set to 1.4[4]	
Fluid Viscosity	Live data acquired from SP system	cP
DPt	Live data acquired from SP system	mbar
DPr	Live data acquired from SP system	mbar
DPppl	Live data acquired from SP system	mbar
Pressure	Live data acquired from SP system	barG
Temperature	Live data acquired (calculated) from SP system	degC
Density	Live data acquired (calculated) from SP system	kg/m3

[4] NOTE: The fluid isentropic exponent was initially fixed at 1, however this caused the PROGNOSIS response to 'freeze' at the previous calculated values. The issue was traced back to the calculation sheet and the standard ISO 5167 [2] calculation block which ceased to produce outputs.
The isentropic exponent calculation in the standard ISO 5167 calculation block includes a division by (k-1) which was causing a calculation error (even though the calculated expansibility factor is not required or used). SWINTON is to identify a solution for this which will avoid any division by zero. The solution will be rolled out into the next version of the PROGNOSIS software.
The expansibility factor ε was set to 'keypad' mode in PROGNOSIS and fixed at 1.

Establishing a Baseline (carried out by SWINTON)

Once the communications link between PROGNOSIS and the SP system was established and verified, the initial diagnostic response was observed using ‘default’ uncertainties and no compensation factors (i.e., the actual meter performance was compared to the expected meter performance based on ISO 5167 [2] predictions including the ‘Urner’ PLR prediction).

The initial response saw PROGNOSIS go in and out of alarm and the following typical pattern was observed:

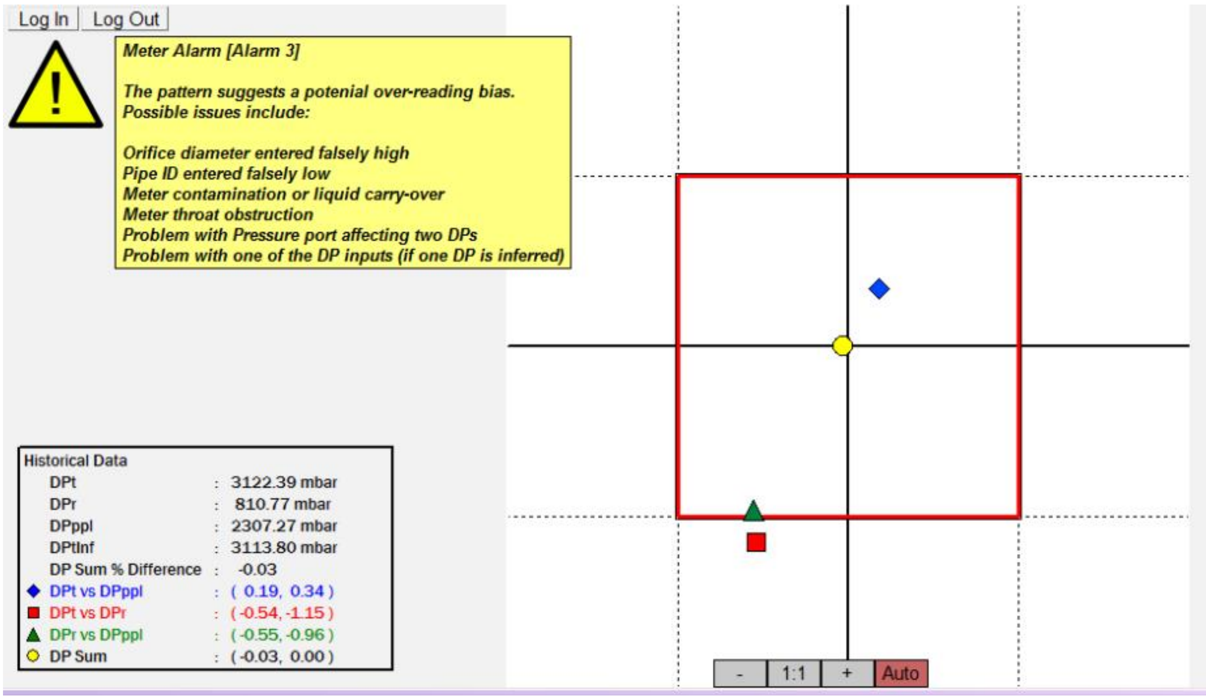


Figure 20 – Initial response with no correction for corner tappings

As the plate was new and undamaged and the meter geometry was confirmed as correct and no DP measurement issue was suspected (due to PROGNOSIS indicating no DP integrity alarm), it was concluded that the corner tapping arrangement was the reason for this response and completely explained a response of this nature.

Observations showed the reported Orifice meter flow rate in agreement with the mag meter and Coriolis meter (references) reported flow rates to within 0.5 %.

The PROGNOSIS DP ratio predictions for an Orifice meter use the ISO 5167 [2] “Urner” equation which based on an upstream pressure port 1D upstream and a downstream pressure port 6D downstream. Such pressure port locations produce ***very*** similar DPs to flange tapped Orifice meters, i.e. the most commonly used Orifice meter design in the western world. However, these tests used a corner tap Orifice meter which has pressure taps in locations different to flange tap Orifice meters. Corner tap pressure ports read a slightly higher PLR than flange tap pressure ports. Hence, PROGNOSIS must modify the ISO / flange tap Orifice meter PLR prediction for use with the different geometry corner tap Orifice meters. These corner tap Orifice meter tests show that the difference between the actual corner tap Orifice meter PLR readings and the ISO flange tapped PLR predictions could be corrected for by a compensation factor (Z) of 0.007.

Below is an example of the diagnostic response with Z = 0.007 entered:

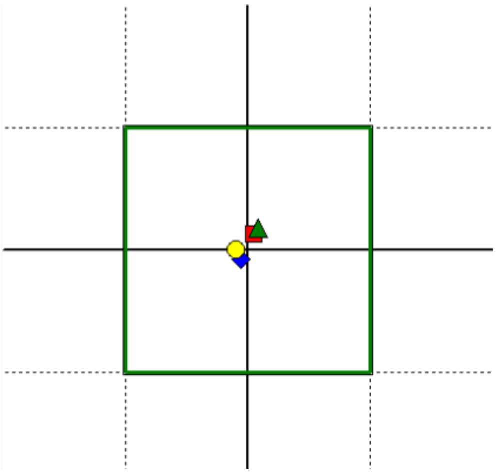


Figure 21 - Baseline response including compensation for corner tappings

It was identified that the four 'points' representing the diagnostic results were very close to the origin and not deviating much from the origin, suggesting that the diagnostic 'variance' settings (representing the uncertainty of each of the 6 diagnostic parameters) could be reduced.

This is an option but not a requirement by the end user. The end user can use the default settings (see the following table) and PROGNOSIS will still monitor for meter malfunctions with reasonably high sensitivity. However, if the operator sees the points are stable at the centre of the box it is an option to increase the sensitivity further to look for smaller problems by further reducing the variance settings as shown here.

Following a short time of observation, alternative variance settings were established and entered into the PROGNOSIS settings. Due to the stable flow and very stable PROGNOSIS response, the PROGNOSIS variances were reduced to:

Table 9 – Settings of the diagnostic parameters during the evaluation test

Parameter	Default settings	Used settings
Mass Trad:	1.0 %	0.7 %
Mass Rec:	2.5 %	1.0 %
Mass PPL:	2.5 %	1.0 %
PLR:	3.0 %	1.5 %
PRR:	2.5 %	1.0 %
RPR:	4.0 %	1.5 %
DP Sum:	1.0 %	0.7 %

The variances in Table 9 stated as 'used settings' were used for all tests.

During each test, the PROGNOSIS software was set to 'archive' producing .csv files recording a number of inputs and outputs and corresponding datestamp. Each line of data is coherent in that the recoded inputs correspond with the recorded outputs (a 'snapshot' of values is taken after each calculation completion).

In order to avoid false alarms due to fluctuating flow rate, the PROGNOSIS software was set to use inputs averaged over 10 seconds. Approximately once per second, the data is polled, calculations performed (using the average of the last ten inputs), the screen updated and all data (inputs and outputs) archived.

Baseline test (carried out by SWINTON)

With the appropriate settings established, the diagnostic baseline was observed and recorded. Below are random PROGNOSIS results for a correctly operating meter at a Reynolds number of approximately 300 000, 5 barG and 20 ˚C.

Observations showed the reported Orifice meter flow rate in agreement with the mag flow (reference) reported flow rate to within 0.5 %.

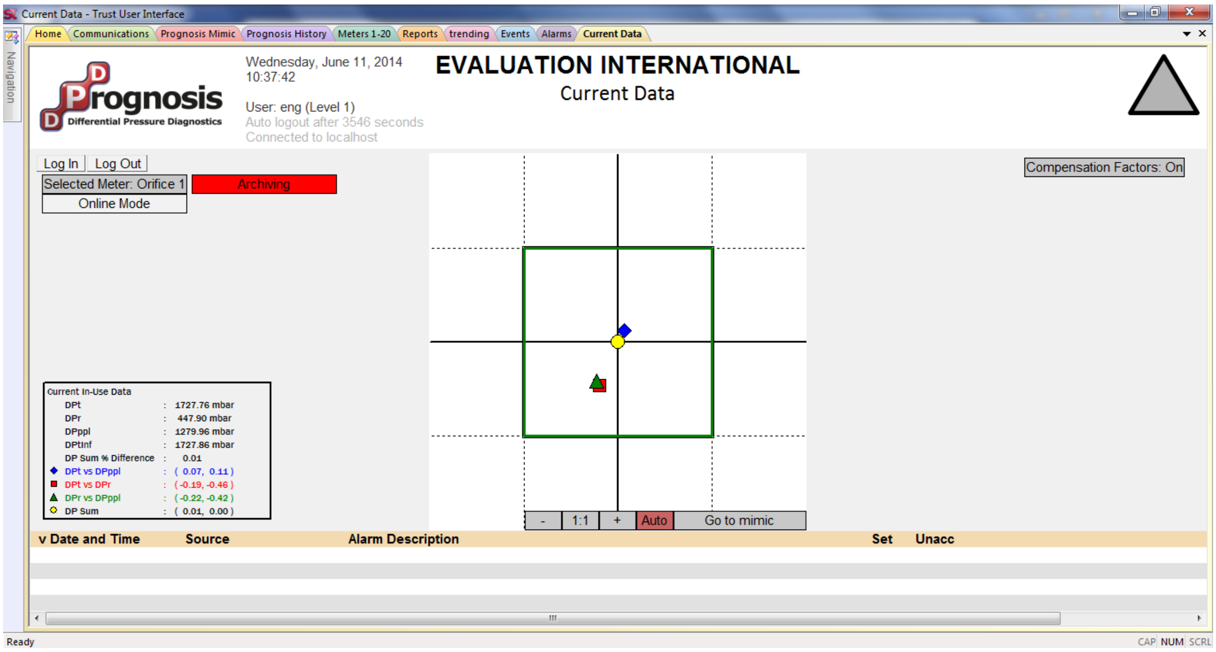


Figure 22 – First result of the baseline test (‘random’ snapshot – 1/2)

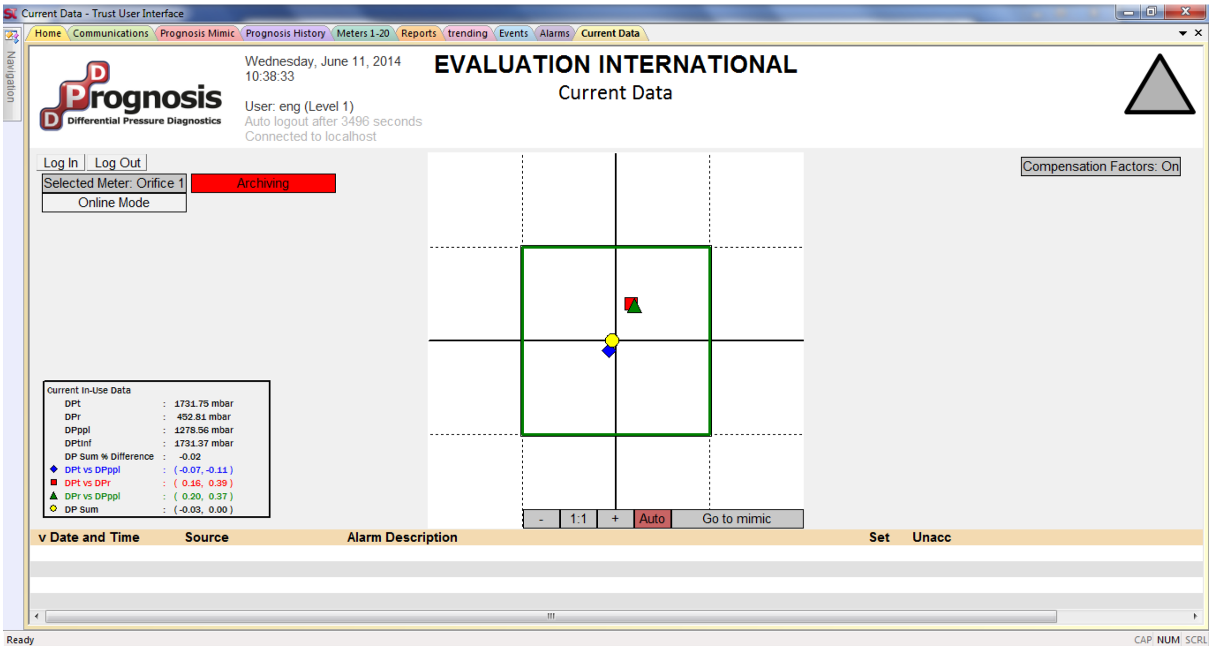


Figure 23 – First result of the baseline test (‘random’ snapshot – 2/2)

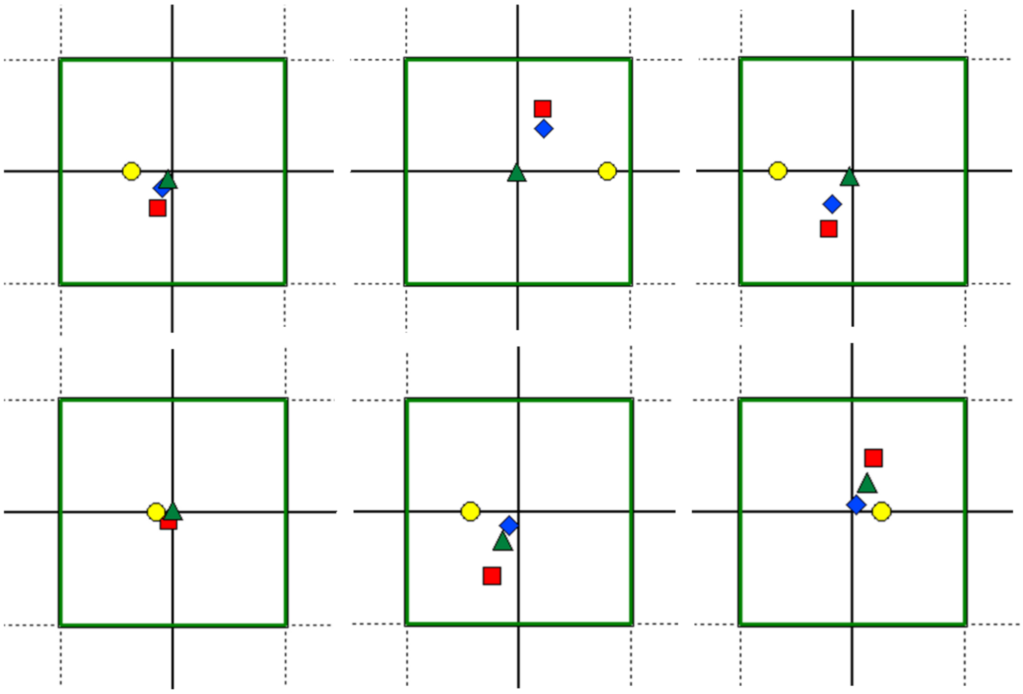


Figure 24 – Example baseline diagnostic responses

The baseline response saw the ‘points’ representing the diagnostic results move around inside the ‘Normalised Diagnostic Box’ (NDB) indicating actual meter performance matching the expected meter performance to within natural (statistically) variances.

4.1.1. Calibration of the Orifice plate

The principle of an orifice flow meter is based on the measurement of the static pressure difference between the upstream and downstream sides. According to the standards ISO 5167 [2] and ASME MFC-3M [7], the mass flow q_m in pipes by using an Orifice plate, nozzle or Venturi tube can be determined with the following equation:

$$q_m = \frac{C_d}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2\Delta p \cdot \rho_1}$$

Here the differential pressure Δp can be measured by the use of a differential pressure transmitter. In addition, the density ρ_1, the pipe diameter D and the Orifice diameter d can be calculated by measuring the fluid temperature and using a linear model for the thermal material expansion. Since the Orifice plate and pipe were made from one material the Orifice diameter to pipe diameter ratio β remains nearly constant. The expansion factor ε for incompressible flow through an Orifice is ε=1.

The discharge coefficient C_d can be calculated by rearranging the upper equation:

$$C_d = \frac{4 \cdot q_m \cdot \sqrt{1-\beta^4}}{\varepsilon \cdot \pi \cdot d^2 \cdot \sqrt{2\Delta p \cdot \rho_1}}$$

An empirical equation for the discharge coefficient based on measurements by different test facilities is presented by Reader-Harris/Gallagher (RHG) [2]:

$$\begin{aligned} C_d = 0.5961 + 0.0261 \cdot \beta^2 - 0.216 \cdot \beta^8 + 0.000521 \left[\frac{\beta \cdot 10^6}{Re_D}\right]^{0.7} \\ +(0.0188 + 0.0063 \cdot A) \cdot \beta^{3.5} \left[\frac{10^6}{Re_D}\right]^{0.3} \\ +(0.043 + 0.080 e^{-10L_1} - 0.123 e^{-7L_1}) \cdot (1 - 0.11 \cdot A) \frac{\beta^4}{1-\beta^4} \\ -0.031 \cdot (M'_2 - 0.8\, {M'_2}^{1.1}) \cdot \beta^{1.3} \end{aligned}$$

The required values **M'₂** and **A** can be calculated according to the standard ISO 5167 [2]:

$$M'_2 = \frac{2 \cdot L'_2}{1-\beta}$$

$$A = \left[\frac{19000 \cdot \beta}{Re_D}\right]^{0.8}$$

For an Orifice plate with corner tappings (as in our case) the two values **L_1** and **L'_2** are given by L_1=0 and L'_2=0.

Calibration measurements at 20 ˚C

As reference case and in order to calibrate the secondary standards (Mag meter, Coriolis flow meter) for the tests, calibration measurements at fixed Reynolds numbers were performed.

(Note: The temperature sensor T_{VM4} in the following figures is installed in a pipeline which was not used for the evaluation tests.)

$I_{min=}$	4.00 mA	4.00 mA	
$I_{max=}$	20.00 mA	20.00 mA	
$q_{min=}$	0.00 kPa	0.00 kg/min	
$q_{max=}$	500.00 kPa	3000.00 kg/min	p/l= **57.62** p/kg= **100.00**

No.	$q_{v ner}$ l/min	$q_{m T,p sl in}$ kg/min	VM4 p_U kPa	slinga in $p_{slinga in}$ kPa	slinga ut $p_{slingan ut}$ kPa	E o H K_1 p/l	$felv_1$ %	RMV3 puls K_2 p/kg	felv2 %	DPt $\delta p_{1 brutto}$ mA	$\delta p_{1 brutto}$ kPa
1	2310.47	2306.29	165.3	64.0	28.3	57.3769	-0.422	99.9637	-0.036	18.2948	446.7124
2	2301.25	2297.09	168.0	66.5	28.2	57.3907	-0.398	99.9456	-0.054	18.1736	442.9253
3	2298.83	2294.68	169.1	68.7	27.9	57.3888	-0.401	99.9618	-0.038	18.1531	442.2848
4	2301.57	2297.41	167.0	65.4	27.8	57.3737	-0.428	99.9494	-0.051	18.1765	443.0144
5	2299.19	2295.05	168.9	68.4	27.6	57.3760	-0.423	99.9558	-0.044	18.1495	442.1713
6	2303.51	2299.36	166.5	64.9	27.5	57.3749	-0.425	99.9560	-0.044	18.2053	443.9166
mv=	**2302.47**	**2298.31**	**167.5**	**66.3**	**27.9**	**57.3802**	**-0.416**	**99.955**	**-0.045**	**18.1921**	**443.504**
w=	11.64	11.61	3.8	4.7	0.9	0.0170	0.029	0.018	0.018	0.1453	4.541
s=	4.28	4.26	1.5	1.9	0.3	0.0075	0.013	0.007	0.007	0.0541	1.691

No.	RMV3 mA I_{2medel} mA	$felv_{I2}$ %	$\rho_{slingan in}$ kg/dm³	$\rho(T_{sl in},p_{sl in})$ kg/m³	$\rho(T_O,p_U)$ kg/m³	$\mu(T_O,p_U)$ Pa*s	VM4 T_{VM4} °C	master 1 $T_{master 1}$ °C	slinga ut $T_{slinga ut}$ °C	t_{gate} s
1	16.2924	-0.061	0.998157	998.1907	998.2369	0.000985	22.79	20.66	20.70	91.062
2	16.2399	-0.088	0.998157	998.1921	998.2384	0.000985	22.79	20.66	20.69	91.412
3	16.2281	-0.080	0.998159	998.1952	998.2410	0.000985	22.79	20.65	20.68	91.524
4	16.2419	-0.086	0.998160	998.1945	998.2408	0.000985	22.80	20.64	20.68	91.399
5	16.2293	-0.086	0.998162	998.1979	998.2438	0.000986	22.80	20.64	20.67	91.509
6	16.2529	-0.081	0.998163	998.1972	998.2436	0.000986	22.81	20.63	20.66	91.322
mv=	**16.2474**	**-0.080**	**0.998157**	**998.195**	**998.241**	**0.000985**	**20.00**	**20.65**	**20.68**	**91.372**
w=	0.0643	0.028	0.000000	0.007	0.007	0.000001	0.02	0.03	0.04	0.461
s=	0.0238	0.010	0.000003	0.003	0.003	0.000000	0.01	0.01	0.01	0.169

	[m]		β:	0.5
	D_p (20°C):	D_p (T):	d_O (m):	
$\delta p_{1 noll}$ (kPa)	0.10226	0.102261	0.051131	
0.0106				

$\delta p_{1 korr}$ kPa	q_v l/s	v_D m/s	$T_{slinga in}$ °C	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$ %
446.7018	38.51	4.69	20.69	485899	971798	0.60696	0.60441	0.422
442.9147	38.35	4.67	20.68	483948	967896	0.60711	0.60441	0.447
442.2742	38.31	4.66	20.67	483326	966652	0.60691	0.60441	0.414
443.0038	38.36	4.67	20.67	483857	967714	0.60714	0.60441	0.451
442.1607	38.32	4.67	20.66	483246	966491	0.60709	0.60441	0.443
443.9060	38.39	4.67	20.66	484102	968205	0.60703	0.60441	0.434
443.4935	**38.37**	**4.67**	**20.67**	**484063**	**968126**	**0.60704**	**0.60441**	**0.435**
4.5411	0.19	0.02	0.03	2653	5307	0.00022	0.00001	0.037
1.6912	0.07	0.01	0.01	963	1927	0.00009	0.00000	0.015

Figure 25 – Result of the calibration measurements at Re = 480 000 (20 ˚C)

$I_{min=}$	4.00 mA	4.00 mA	
$I_{max=}$	20.00 mA	20.00 mA	
$q_{min=}$	0.00 kPa	0.00 kg/min	
$q_{max=}$	500.00 kPa	3000.00 kg/min	p/l= **57.62** p/kg= **100.00**

No.	$q_{v ner}$ l/min	$q_{m T,p sl in}$ kg/min	VM4 p_U kPa	slinga in $p_{slinga in}$ kPa	slinga ut $p_{slingan ut}$ kPa	E o H K_1 p/l	$felv_1$ %	RMV3 puls K_2 p/kg	felv2 %	DPt $\delta p_{1 brutto}$ mA	$\delta p_{1 brutto}$ kPa
1	1888.32	1885.14	343.5	271.0	211.8	57.3908	-0.398	99.9481	-0.052	13.5383	298.0731
2	1890.35	1887.17	342.4	269.2	212.7	57.3912	-0.397	99.9625	-0.037	13.5555	298.6104
3	1889.87	1886.70	342.7	270.1	212.1	57.3979	-0.386	99.9462	-0.054	13.5523	298.5097
4	1891.22	1888.05	342.2	268.9	212.7	57.3944	-0.391	99.9520	-0.048	13.5650	298.9058
5	1889.00	1885.83	343.1	270.5	211.7	57.3707	-0.433	99.9478	-0.052	13.5442	298.2572
6	1891.79	1888.63	342.0	268.7	212.9	57.3957	-0.389	99.9583	-0.042	13.5699	299.0602
mv=	**1890.09**	**1886.92**	**342.7**	**269.7**	**212.3**	**57.3901**	**-0.399**	**99.952**	**-0.048**	**13.5542**	**298.569**
w=	3.47	3.48	1.5	2.3	1.2	0.0271	0.047	0.016	0.016	0.0316	0.987
s=	1.31	1.31	0.6	0.9	0.5	0.0099	0.017	0.007	0.007	0.0120	0.375

No.	RMV3 mA I_{2medel} mA	$felv_{I2}$ %	$\rho_{slingan in}$ kg/dm³	$\rho(T_{sl in},p_{sl in})$ kg/m³	$\rho(T_O,p_U)$ kg/m³	$\mu(T_O,p_U)$ Pa*s	VM4 T_{VM4} °C	master 1 $T_{master 1}$ °C	slinga ut $T_{slinga ut}$ °C	t_{gate} s
1	14.0435	-0.092	0.998191	998.3192	998.3522	0.000989	22.91	20.50	20.54	111.423
2	14.0559	-0.077	0.998192	998.3193	998.3527	0.000989	22.92	20.49	20.53	111.285
3	14.0516	-0.095	0.998194	998.3222	998.3553	0.000989	22.93	20.48	20.52	111.331
4	14.0596	-0.087	0.998195	998.3230	998.3564	0.000989	22.94	20.47	20.51	111.233
5	14.0467	-0.097	0.998197	998.3255	998.3586	0.000989	22.94	20.47	20.50	111.383
6	14.0628	-0.085	0.998199	998.3262	998.3596	0.000990	22.96	20.46	20.50	111.200
mv=	**14.0534**	**-0.089**	**0.998191**	**998.323**	**998.356**	**0.000989**	**20.00**	**20.48**	**20.52**	**111.309**
w=	0.0192	0.020	0.000000	0.007	0.007	0.000001	0.05	0.04	0.04	0.223
s=	0.0074	0.007	0.000003	0.003	0.003	0.000000	0.02	0.02	0.02	0.086

	[m]		β:	0.5
	D_p (20°C):	D_p (T):	d_O (m):	
$\delta p_{1 noll}$ (kPa)	0.10226	0.102261	0.05113	
0.0106				

$\delta p_{1 korr}$ kPa	q_v l/s	v_D m/s	$T_{slinga in}$ °C	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$ %
298.0625	31.47	3.83	20.53	395663	791326	0.60732	0.60463	0.446
298.5998	31.51	3.84	20.52	396042	792084	0.60742	0.60463	0.463
298.4991	31.50	3.84	20.51	395833	791667	0.60738	0.60463	0.455
298.8952	31.52	3.84	20.50	396057	792113	0.60741	0.60463	0.461
298.2466	31.48	3.83	20.49	395509	791018	0.60735	0.60463	0.451
299.0496	31.53	3.84	20.49	396029	792057	0.60743	0.60463	0.465
298.5588	**31.50**	**3.84**	**20.51**	**395855**	**791711**	**0.60739**	**0.60463**	**0.457**
0.9871	0.06	0.01	0.04	547	1095	0.00011	0.00000	0.019
0.3750	0.02	0.00	0.01	229	459	0.00004	0.00000	0.007

Figure 26 – Result of the calibration measurements at Re = 400 000 (20 ˚C)

$I_{min=}$ 4.00 mA 4.00 mA
$I_{max=}$ 20.00 mA 20.00 mA
$q_{min=}$ 0.00 kPa 0.00 kg/min
p/l= **57.62** p/kg= **100.00** $q_{max=}$ 500.00 kPa 3000.00 kg/min

			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	$q_{v\,ner}$	$q_{m\,T,p\,sl\,in}$	p_U	$p_{slinga\,in}$	$p_{slingan\,ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1\,brutto}$	$\delta p_{1\,brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan\,in}$	$\rho(T_{sl\,in},p_{sl\,in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master\,1}$	$T_{slinga\,ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm^3**	**kg/m^3**	**kg/m^3**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	1434.66	1432.34	318.7	272.3	227.6	57.4277	-0.334	99.9512	-0.049	9.4974	171.7925	11.6319	-0.082	0.998250	998.3787	998.3999	0.000995	23.03	20.21	20.27	146.655
2	1435.85	1433.53	317.2	270.4	228.2	57.4387	-0.315	99.9602	-0.040	9.5080	172.1240	11.6390	-0.071	0.998253	998.3815	998.4029	0.000996	23.04	20.20	20.25	146.509
3	1434.85	1432.53	317.9	271.5	227.6	57.4199	-0.347	99.9495	-0.050	9.5006	171.8925	11.6328	-0.083	0.998257	998.3858	998.4070	0.000996	23.05	20.18	20.23	146.636
4	1434.20	1431.89	316.9	270.3	227.6	57.4311	-0.328	99.9574	-0.043	9.4930	171.6554	11.6298	-0.078	0.998260	998.3884	998.4097	0.000997	23.07	20.16	20.22	146.677
5	1434.58	1432.28	318.2	271.8	227.9	57.4242	-0.340	99.9492	-0.051	9.4976	171.8014	11.6312	-0.086	0.998264	998.3925	998.4138	0.000997	23.08	20.15	20.20	146.663
6	1434.70	1432.40	317.5	270.7	228.6	57.4331	-0.324	99.9653	-0.035	9.5003	171.8832	11.6330	-0.072	0.998267	998.3952	998.4166	0.000997	23.09	20.13	20.18	146.626
mv=	**1434.81**	**1432.49**	**317.7**	**271.2**	**227.9**	**57.4291**	**-0.331**	**99.955**	**-0.045**	**9.4995**	**171.858**	**11.6330**	**-0.079**	**0.998250**	**998.387**	**998.408**	**0.000997**	**20.00**	**20.17**	**20.22**	**146.628**
w=	1.65	1.64	1.8	2.1	1.0	0.0188	0.033	0.016	0.016	0.0150	0.469	0.0092	0.015	0.000000	0.016	0.017	0.000002	0.06	0.08	0.09	0.168
s=	0.55	0.55	0.7	0.8	0.4	0.0067	0.012	0.007	0.007	0.0050	0.156	0.0032	0.006	0.000006	0.006	0.006	0.000001	0.02	0.03	0.03	0.061

[m] β: 0.5
D_p (20°C): D_p (T): d_O (m):
$\delta p_{1\,noll}$ (kPa) 0.10226 0.10226 0.05113
0.0007

$\delta p_{1\,korr}$	q_v	v_D	$T_{slinga\,in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
171.7918	23.91	2.91	20.25	298585	597170	0.60781	0.60497	0.470
172.1233	23.93	2.91	20.23	298704	597408	0.60773	0.60497	0.456
171.8918	23.91	2.91	20.21	298364	596728	0.60771	0.60497	0.454
171.6547	23.90	2.91	20.20	298122	596244	0.60786	0.60497	0.478
171.8007	23.91	2.91	20.18	298082	596165	0.60776	0.60497	0.462
171.8825	23.91	2.91	20.16	297998	595996	0.60767	0.60497	0.446
171.8575	**23.91**	**2.91**	**20.20**	**298309**	**596618**	**0.60776**	**0.60497**	**0.461**
0.4686	0.03	0.00	0.08	706	1412	0.00019	0.00000	0.031
0.1556	0.01	0.00	0.03	289	578	0.00007	0.00000	0.011

Figure 27 – Result of the calibration measurements at Re = 300 000 (20 °C)

$I_{min=}$ 4.00 mA 4.00 mA
$I_{max=}$ 20.00 mA 20.00 mA
$q_{min=}$ 0.00 kPa 0.00 kg/min
p/l= **57.62** p/kg= **100.00** $q_{max=}$ 500.00 kPa 3000.00 kg/min

			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	$q_{v\,ner}$	$q_{m\,T,p\,sl\,in}$	p_U	$p_{slinga\,in}$	$p_{slingan\,ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1\,brutto}$	$\delta p_{1\,brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan\,in}$	$\rho(T_{sl\,in},p_{sl\,in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master\,1}$	$T_{slinga\,ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm^3**	**kg/m^3**	**kg/m^3**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	1193.39	1191.55	340.7	305.5	268.0	57.4373	-0.317	99.9469	-0.053	7.8011	118.7843	10.3511	-0.047	0.998314	998.4583	998.4744	0.001003	23.13	19.89	20.02	176.304
2	1192.59	1190.76	340.1	304.8	268.2	57.4604	-0.277	99.9580	-0.042	7.7967	118.6478	10.3474	-0.039	0.998322	998.4664	998.4826	0.001004	23.14	19.85	19.95	176.392
3	1190.68	1188.86	340.7	305.6	267.4	57.4488	-0.297	99.9460	-0.054	7.7841	118.2525	10.3363	-0.054	0.998335	998.4793	998.4954	0.001006	23.16	19.79	19.90	176.705
4	1191.38	1189.58	339.6	304.3	268.3	57.4504	-0.294	99.9582	-0.042	7.7894	118.4185	10.3410	-0.040	0.998346	998.4895	998.5057	0.001007	23.17	19.71	19.84	176.571
5	1189.72	1187.94	341.1	306.1	267.6	57.4338	-0.323	99.9499	-0.050	7.7778	118.0567	10.3315	-0.052	0.998358	998.5026	998.5186	0.001008	23.19	19.71	19.78	176.846
6	1190.45	1188.68	340.1	304.8	268.3	57.4532	-0.290	99.9568	-0.043	7.7824	118.2000	10.3360	-0.043	0.998369	998.5133	998.5294	0.001010	23.19	19.67	19.73	176.708
mv=	**1191.37**	**1189.56**	**340.4**	**305.2**	**268.0**	**57.4473**	**-0.300**	**99.953**	**-0.047**	**7.7886**	**118.393**	**10.3405**	**-0.046**	**0.998314**	**998.485**	**998.501**	**0.001006**	**20.00**	**19.77**	**19.87**	**176.588**
w=	3.67	3.61	1.5	1.8	0.9	0.0267	0.046	0.012	0.012	0.0233	0.728	0.0196	0.015	0.000000	0.055	0.055	0.000007	0.05	0.22	0.29	0.543
s=	1.39	1.36	0.6	0.7	0.4	0.0100	0.017	0.006	0.006	0.0089	0.279	0.0075	0.006	0.000021	0.021	0.021	0.000003	0.02	0.09	0.11	0.207

[m] β: 0.5
D_p (20°C): D_p (T): d_O (m):
$\delta p_{1\,noll}$ (kPa) 0.10226 0.10226 0.05113
-0.0013

$\delta p_{1\,korr}$	q_v	v_D	$T_{slinga\,in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
118.7856	19.89	2.42	19.94	246518	493036	0.60806	0.60523	0.467
118.6491	19.88	2.42	19.89	246108	492217	0.60800	0.60523	0.458
118.2538	19.84	2.42	19.83	245348	490695	0.60804	0.60523	0.464
118.4198	19.86	2.42	19.78	245178	490356	0.60798	0.60524	0.453
118.0580	19.83	2.41	19.72	244480	488961	0.60806	0.60524	0.467
118.2013	19.84	2.42	19.67	244299	488598	0.60807	0.60524	0.468
118.3946	**19.86**	**2.42**	**19.81**	**245322**	**490644**	**0.60803**	**0.60523**	**0.463**
0.7275	0.06	0.01	0.27	2219	4439	0.00010	0.00001	0.015
0.2788	0.02	0.00	0.10	875	1749	0.00004	0.00001	0.006

Figure 28 – Result of the calibration measurements at Re = 250 000 (20 °C)

$I_{min=}$ 4.00 mA 4.00 mA
$I_{max=}$ 20.00 mA 20.00 mA
$q_{min=}$ 0.00 kPa 0.00 kg/min
p/l= **57.62** p/kg= **100.00** $q_{max=}$ 500.00 kPa 3000.00 kg/min

			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	$q_{v ner}$	$q_{m T,p sl in}$	p_U	$p_{slinga in}$	$p_{slingan ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1 brutto}$	$\delta p_{1 brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan in}$	$\rho(T_{sl in},p_{sl in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master 1}$	$T_{slinga ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm³**	**kg/m³**	**kg/m³**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	976.13	974.72	345.5	318.8	285.5	57.4592	-0.279	99.9395	-0.060	6.5397	79.3650	9.2001	0.047	0.998407	998.5571	998.5694	0.001014	23.24	19.43	19.55	215.542
2	976.47	975.08	345.0	318.2	286.1	57.4823	-0.239	99.9461	-0.054	6.5413	79.4161	9.2019	0.044	0.998419	998.5693	998.5816	0.001016	23.24	19.37	19.49	215.429
3	977.51	976.13	346.1	319.5	286.7	57.4552	-0.286	99.9361	-0.064	6.5474	79.6065	9.2078	0.049	0.998432	998.5827	998.5950	0.001017	23.26	19.31	19.42	215.236
4	977.58	976.21	345.1	318.3	287.1	57.4680	-0.264	99.9523	-0.048	6.5483	79.6341	9.2086	0.057	0.998443	998.5937	998.6060	0.001019	23.27	19.25	19.37	215.184
5	976.37	975.01	345.5	318.8	286.3	57.4733	-0.255	99.9419	-0.058	6.5410	79.4058	9.2016	0.045	0.998455	998.6060	998.6182	0.001020	23.29	19.19	19.30	215.487
6	976.58	975.23	345.1	318.3	286.6	57.4641	-0.271	99.9560	-0.044	6.5431	79.4710	9.2035	0.058	0.998464	998.6143	998.6265	0.001022	23.29	19.15	19.25	215.404
mv=	**976.78**	**975.40**	**345.4**	**318.7**	**286.4**	**57.4670**	**-0.266**	**99.945**	**-0.055**	**6.5435**	**79.483**	**9.2039**	**0.050**	**0.998407**	**998.587**	**998.599**	**0.001018**	**20.00**	**19.28**	**19.40**	**215.380**
w=	1.46	1.49	1.2	1.3	1.7	0.0271	0.047	0.020	0.020	0.0086	0.269	0.0085	0.014	0.000000	0.057	0.057	0.000007	0.06	0.29	0.30	0.359
s=	0.62	0.62	0.4	0.5	0.6	0.0098	0.017	0.008	0.008	0.0036	0.112	0.0035	0.006	0.000022	0.022	0.022	0.000003	0.02	0.11	0.11	0.141

[m] β: 0.5
D_p (20°C): D_p (T): d_O (m):
$\delta p_{1 noll}$ (kPa) 0.10226 0.102259 0.051129
0.0156

$\delta p_{1 korr}$	q_v	v_D	$T_{slinga in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
79.3494	16.27	1.98	19.48	199416	398832	0.60856	0.60555	0.498
79.4005	16.27	1.98	19.42	199184	398367	0.60859	0.60555	0.502
79.5909	16.29	1.98	19.35	199083	398166	0.60851	0.60555	0.489
79.6185	16.29	1.98	19.30	198816	397633	0.60845	0.60555	0.479
79.3902	16.27	1.98	19.24	198274	396548	0.60857	0.60556	0.498
79.4554	16.28	1.98	19.19	198110	396220	0.60846	0.60556	0.479
79.4675	**16.28**	**1.98**	**19.33**	**198814**	**397627**	**0.60852**	**0.60555**	**0.491**
0.2691	0.02	0.00	0.29	1306	2612	0.00013	0.00001	0.023
0.1119	0.01	0.00	0.11	521	1043	0.00006	0.00000	0.010

Figure 29 – Result of the calibration measurements at Re = 200 000 (20 ˚C)

$I_{min=}$ 4.00 mA 4.00 mA
$I_{max=}$ 20.00 mA 20.00 mA
$q_{min=}$ 0.00 kPa 0.00 kg/min
p/l= **57.62** p/kg= **100.00** $q_{max=}$ 500.00 kPa 3000.00 kg/min

			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	$q_{v ner}$	$q_{m T,p sl in}$	p_U	$p_{slinga in}$	$p_{slingan ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1 brutto}$	$\delta p_{1 brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan in}$	$\rho(T_{sl in},p_{sl in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master 1}$	$T_{slinga ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm³**	**kg/m³**	**kg/m³**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	484.16	483.49	309.0	297.1	276.5	57.5406	-0.138	99.9098	-0.090	4.6221	19.4392	6.5787	0.017	0.998482	998.6223	998.6278	0.001024	23.33	19.06	19.13	123.264
2	483.06	482.39	308.7	296.9	275.1	57.5369	-0.144	99.8958	-0.104	4.6188	19.3378	6.5718	-0.023	0.998483	998.6233	998.6287	0.001024	23.34	19.06	19.13	124.764
3	484.53	483.86	308.5	296.6	276.9	57.5480	-0.125	99.8951	-0.105	4.6222	19.4441	6.5803	0.001	0.998481	998.6211	998.6266	0.001024	23.34	19.07	19.15	124.122
4	484.45	483.78	308.0	296.2	277.3	57.5332	-0.151	99.9130	-0.087	4.6232	19.4759	6.5806	0.031	0.998475	998.6157	998.6212	0.001023	23.36	19.12	19.12	124.150
5	483.23	482.56	308.3	296.4	275.5	57.4934	-0.220	99.8992	-0.101	4.6191	19.3461	6.5725	-0.029	0.998470	998.6106	998.6161	0.001022	23.36	19.15	19.13	124.675
6	484.24	483.56	308.7	296.8	276.8	57.5064	-0.197	99.9065	-0.093	4.6215	19.4211	6.5786	-0.003	0.998467	998.6072	998.6126	0.001022	23.37	19.16	19.15	123.233
mv=	**483.94**	**483.27**	**308.5**	**296.6**	**276.3**	**57.5264**	**-0.162**	**99.903**	**-0.097**	**4.6211**	**19.411**	**6.5771**	**-0.001**	**0.998482**	**998.617**	**998.622**	**0.001023**	**20.00**	**19.10**	**19.14**	**124.035**
w=	1.47	1.47	1.0	1.0	2.2	0.0546	0.095	0.018	0.018	0.0044	0.138	0.0088	0.061	0.000000	0.016	0.016	0.000002	0.04	0.10	0.03	1.531
s=	0.64	0.64	0.4	0.4	0.9	0.0215	0.037	0.008	0.008	0.0018	0.056	0.0039	0.023	0.000007	0.007	0.007	0.000001	0.02	0.04	0.01	0.663

[m] β: 0.5
D_p (20°C): D_p (T): d_O (m):
$\delta p_{1 noll}$ (kPa) 0.10226 0.102258 0.051129
0.0197

$\delta p_{1 korr}$	q_v	v_D	$T_{slinga in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
19.4195	8.07	0.98	19.10	97998	195996	0.61018	0.60692	0.538
19.3181	8.05	0.98	19.10	97761	195522	0.61039	0.60693	0.571
19.4244	8.08	0.98	19.11	98084	196168	0.61057	0.60692	0.603
19.4562	8.07	0.98	19.13	98131	196262	0.60997	0.60692	0.502
19.3264	8.05	0.98	19.16	97947	195894	0.61047	0.60692	0.585
19.4014	8.07	0.98	19.18	98197	196393	0.61056	0.60692	0.601
19.3910	**8.07**	**0.98**	**19.13**	**98020**	**196039**	**0.61036**	**0.60692**	**0.566**
0.1381	0.02	0.00	0.08	436	871	0.00061	0.00001	0.100
0.0562	0.01	0.00	0.03	155	310	0.00024	0.00000	0.039

Figure 30 – Result of the calibration measurements at Re = 100 000 (20 ˚C)

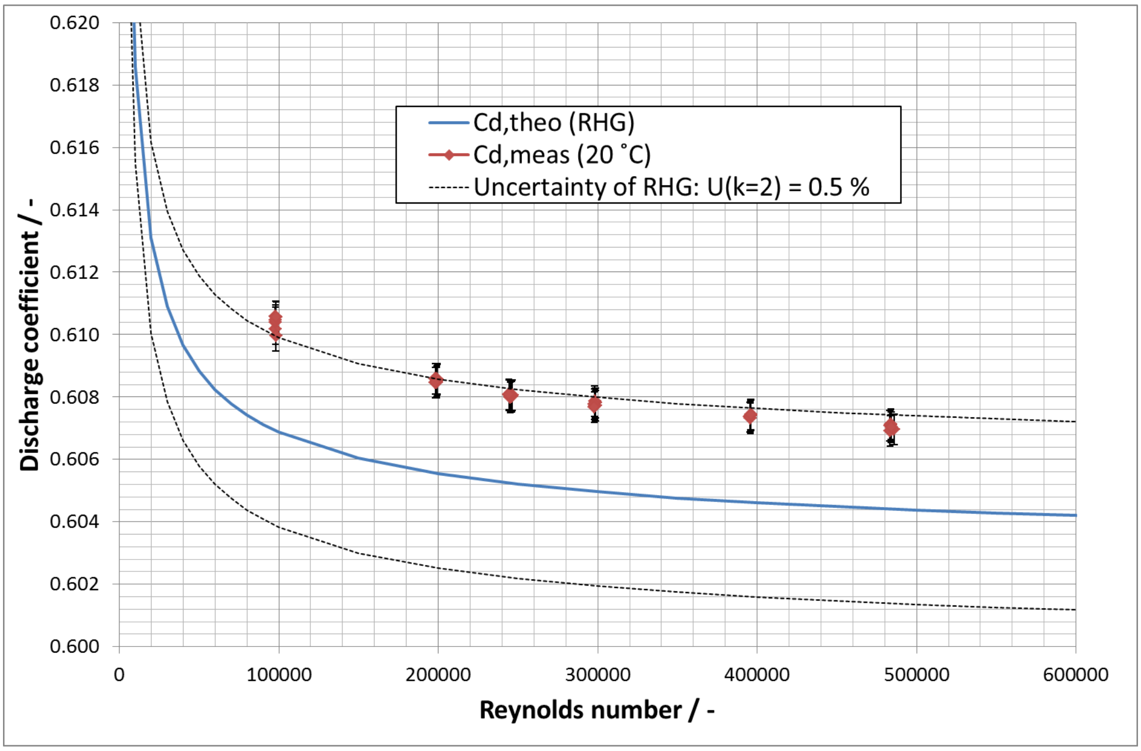


Figure 31 – Results of the calibration measurements (measured discharge coefficient as function of the *Re* number in comparison with the theoretical values according to the RHG equation) at 20 ˚C

It can be seen from the diagram that all measured discharge coefficients have an offset from the theoretical calibration curve (RHG-equation) of approximately 0.45 % for the lower flow rates and approximately 0.55 % for the higher flow rates. As a side note, the RHG-equation has an extended uncertainty of U(k=2) = 0.5 % (0.2 ≤ β ≤ 0.6) and is only valid for calibration measurements with fully developed flow profiles.

The used calibration test facility has an extended measurement uncertainty of U(k=2) = 0.06. This uncertainty is also presented in Figure 31 (black error bars) and it can be seen that the measurements are in good agreement to the theoretical assumptions.

4.2. Test 2 – Influence of an incorrect set inlet pipe diameter (D) value

Objective – determine whether the DUT detects that the pipe diameter was changed.
Criteria – DUT should react in accordance with the manufacturers' specifications.

a) *Incorrectly entered pipe diameter, D = 103.26 mm ('keypad entry error')*
b) *Incorrectly entered pipe diameter, D = 104.26 mm*
c) *Incorrectly entered pipe diameter, D = 120.26 mm ('keypad entry error')*

d) *Incorrectly entered pipe diameter D = 101.26 mm ('keypad entry error')*
e) *Incorrectly entered pipe diameter D = 100.26 mm*

The pipe inner diameter was incorrectly entered into the LabView program. The actual pipe inner diameter was 102.26 mm. The tests were carried out at Reynolds number of approximately 300 000, at a temperature of 20 ˚C and at a pressure of 5barG.

a) Incorrectly entered pipe diameter, D = 103.26 mm

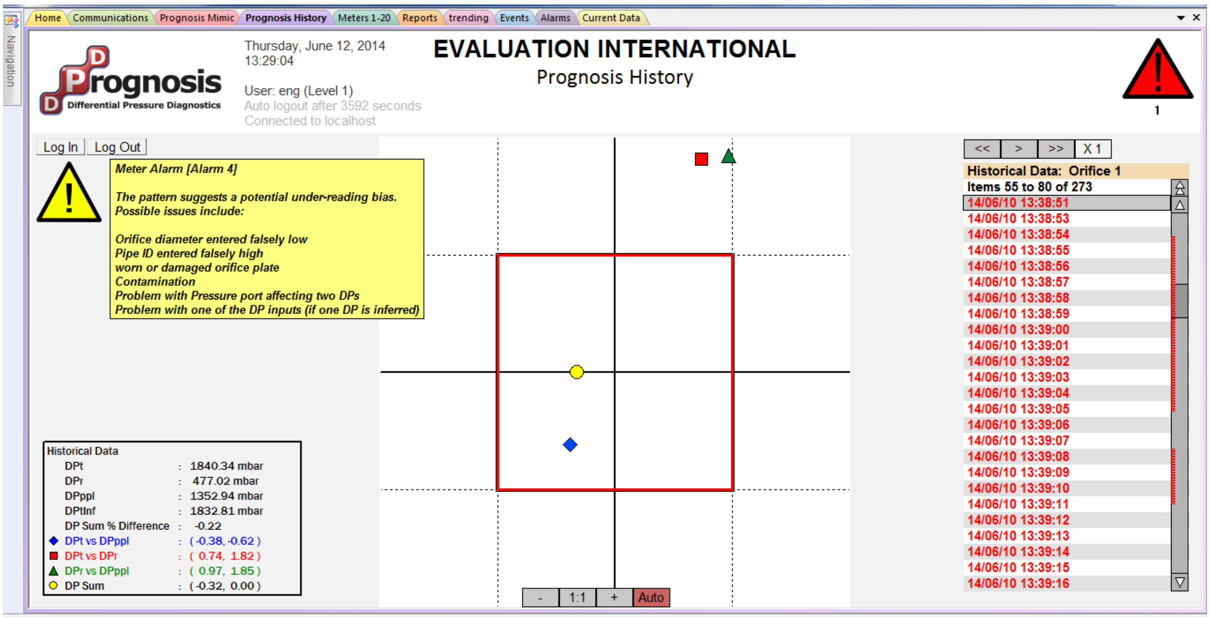


Figure 32 – Snapshot for the test with the incorrectly entered pipe diameter (D = 103.26 mm)

This error in pipe inner diameter of +1 % caused a negative bias in reported flow rate of -0.15 %. PROGNOSIS produced an alarm with the shortlist of possible causes including 'Pipe ID entered falsely high'.

b) Incorrectly entered pipe diameter, D = 104.26 mm

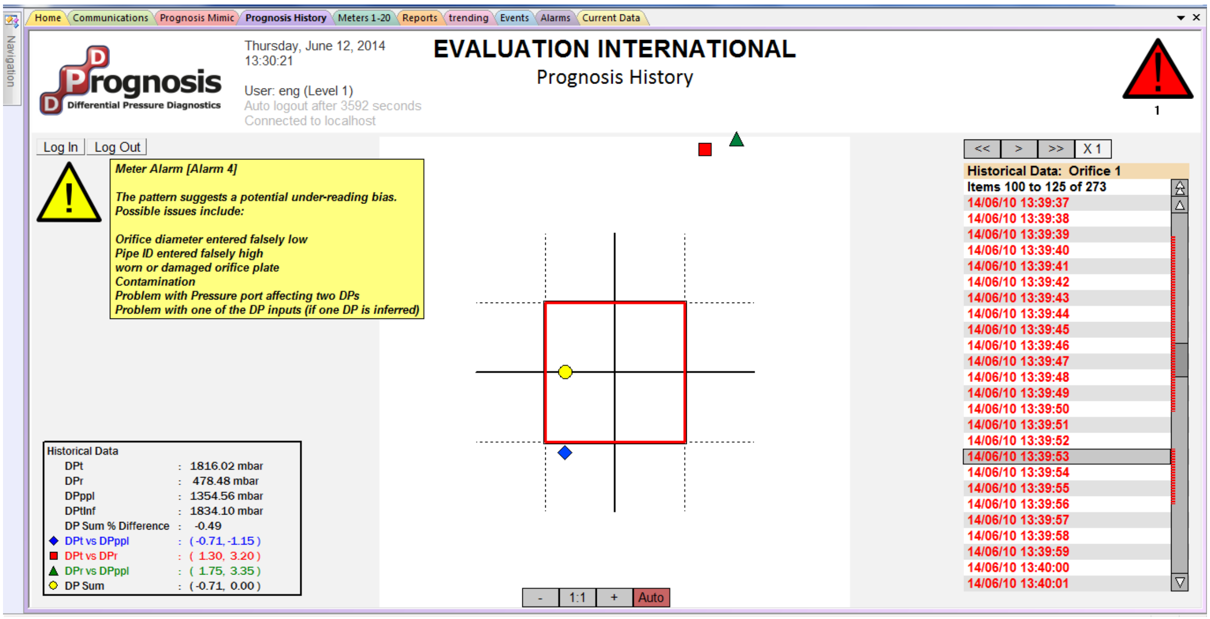


Figure 33 – Snapshot for the test with the incorrectly entered pipe diameter (D = 104.26 mm)

This error in pipe inner diameter of +2 % caused a negative bias in reported flow rate of -0.3 %. PROGNOSIS produced an alarm with the shortlist of possible causes including 'Pipe ID entered falsely high'.

c) Incorrectly entered pipe diameter, D = 120.26 mm

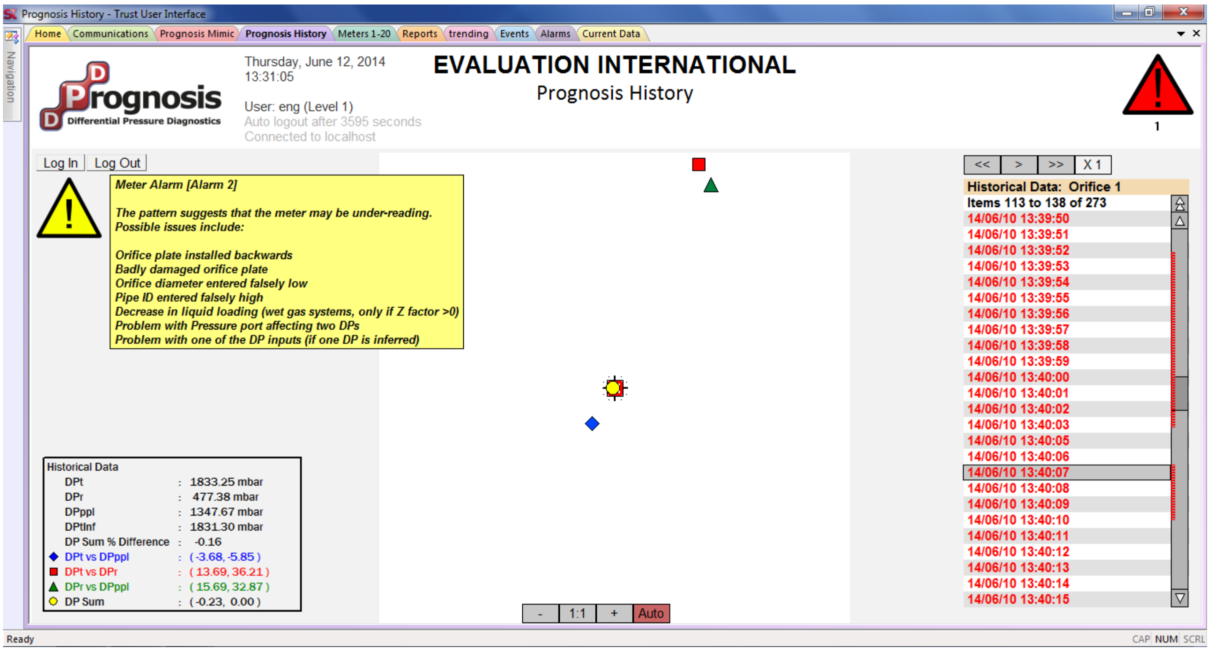


Figure 34 – Snapshot for the test with the incorrectly entered pipe diameter (D = 120.26 mm)

This error in pipe inner diameter of +17.6 % caused a negative bias in reported flow rate of -2 %. PROGNOSIS produced an alarm with the shortlist of possible causes including 'Pipe ID entered falsely high'.

d) Incorrectly entered pipe diameter, D = 101.26 mm

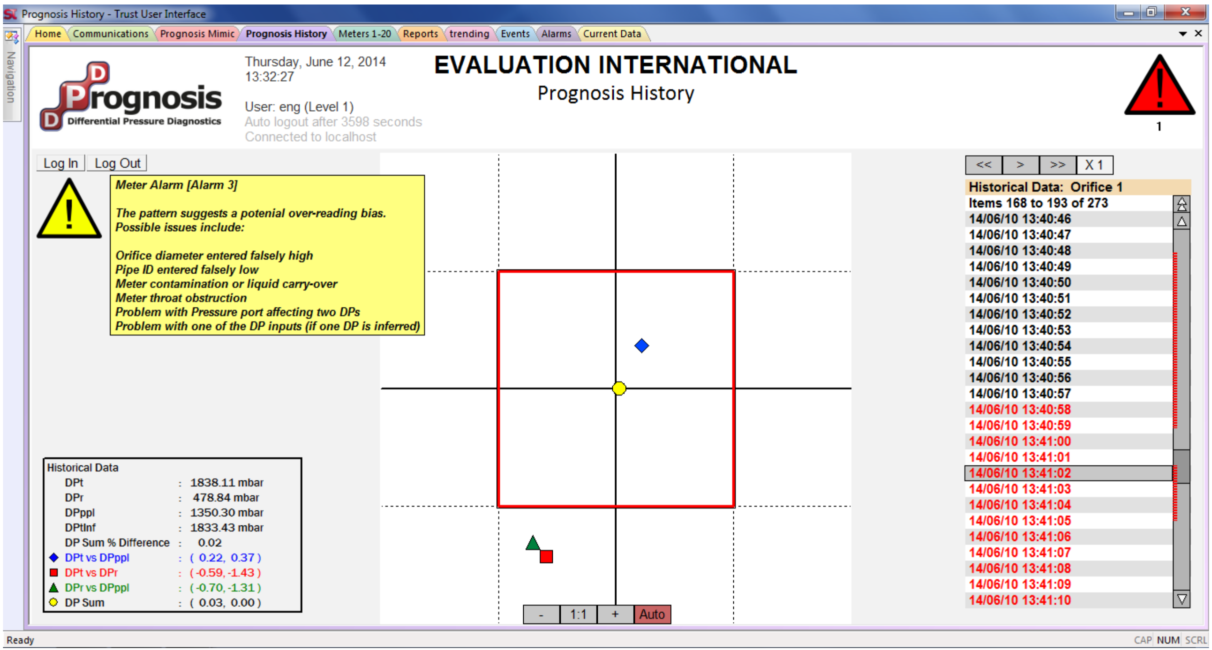


Figure 35 – Snapshot for the test with the incorrectly entered pipe diameter (D = 101.26 mm)

This error in pipe inner diameter of -1 % caused a positive bias in reported flow rate of +0.16 %. PROGNOSIS produced an alarm with the shortlist of possible causes including 'Pipe ID entered falsely low'.

e) Incorrectly entered pipe diameter, D = 100.26 mm

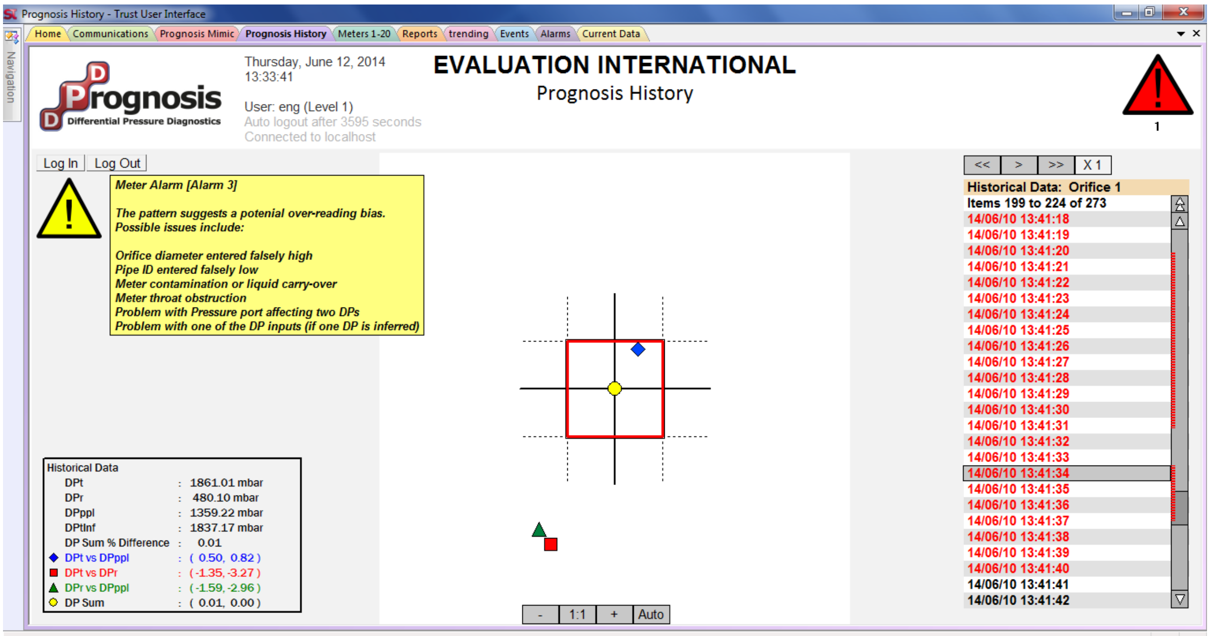


Figure 36 – Snapshot for the test with the incorrectly entered pipe diameter (D = 100.26 mm)

This error in pipe inner diameter of -2 % caused a positive bias in reported flow rate of +0.32 %. PROGNOSIS produced an alarm with the shortlist of possible causes including 'Pipe ID entered falsely low'.

Result: In each test case PROGNOSIS provided a shortlist of 'possible causes' including the 'right error indication', that means: 'Pipe ID entered falsely high' or 'Pipe ID entered falsely low'.

4.3. Test 3 – Influence of an incorrect set Orifice diameter (d) value

Objective – determine whether the DUT detects that the Orifice diameter was changed.
Criteria – DUT should react in accordance with the manufacturers' specifications.

a) *Incorrectly entered Orifice diameter, d = 52.13 mm ('keypad entry error')*
b) *Incorrectly entered Orifice diameter, d = 53.13 mm*
c) *Incorrectly entered Orifice diameter, d = 61.13 mm ('keypad entry error')*

d) *Incorrectly entered Orifice diameter, d = 50.13 mm*
e) *Incorrectly entered Orifice diameter, d = 41.13 mm ('keypad entry error')*

The Orifice diameter was incorrectly entered into the LabView program. The actual orifice diameter was 51.13 mm. The tests were carried out at Reynolds number of approximately 300000, at a temperature of 20 ˚C and at a pressure of 5barG.

a) Incorrectly entered Orifice diameter, d = 52.13 mm

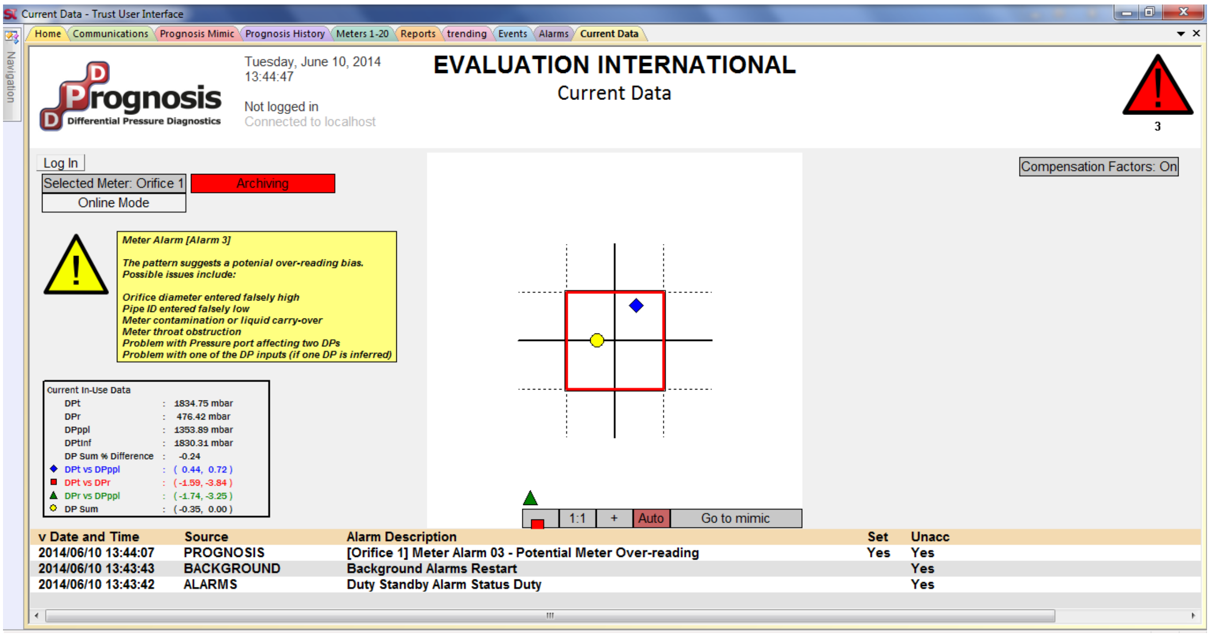


Figure 37 – Snapshot for the test with the incorrectly entered Orifice diameter (D = 52.13 mm)

This error in Orifice diameter of +2 % caused a positive bias in reported flow rate of +4.3 %. PROGNOSIS produced an alarm with the shortlist of possible causes including 'Orifice diameter entered falsely high'.

b) Incorrectly entered Orifice diameter, d = 53.13 mm

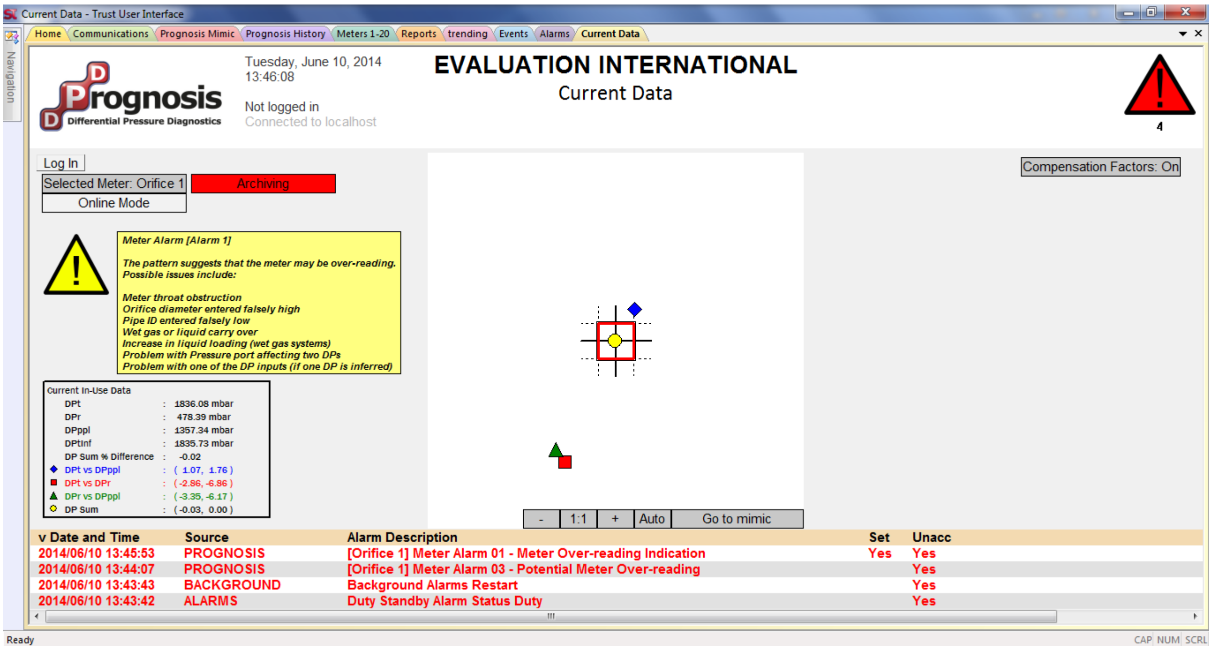


Figure 38 – Snapshot for the test with the incorrectly entered Orifice diameter (D = 53.13 mm)

This error in Orifice diameter of +4% caused a positive bias in reported flow rate of +8.7%. PROGNOSIS produced an alarm with the shortlist of possible causes including ‘Orifice diameter entered falsely high’.

c) Incorrectly entered Orifice diameter, d = 61.13 mm

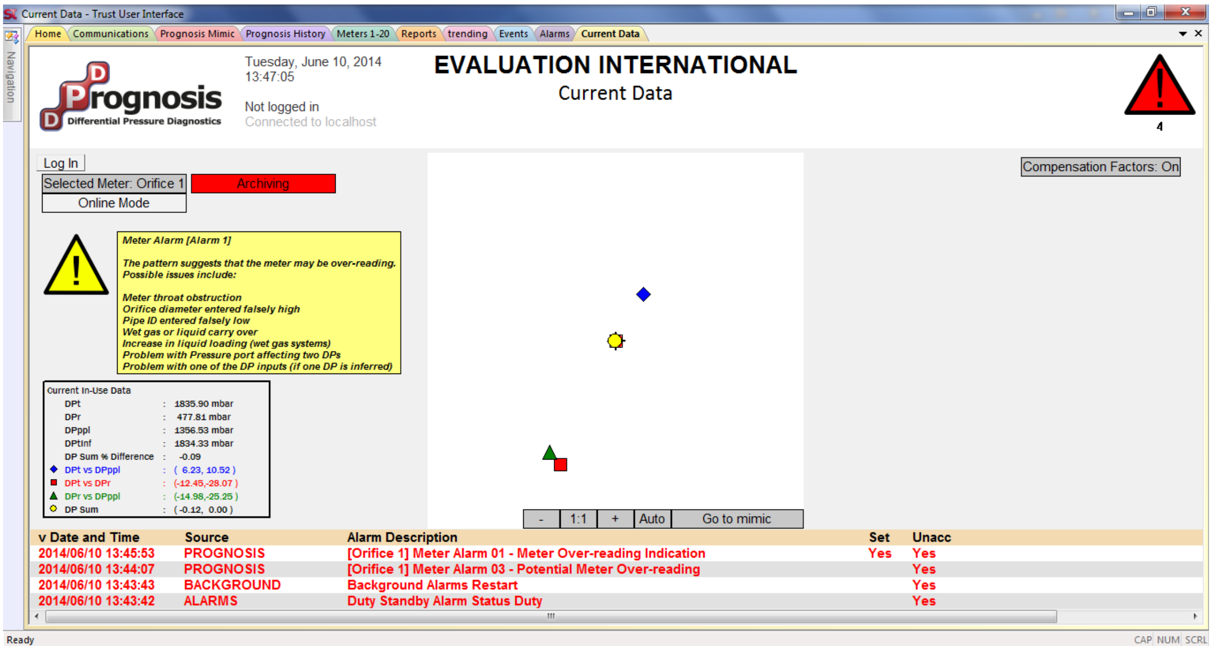


Figure 39 – Snapshot for the test with the incorrectly entered Orifice diameter (D = 61.13 mm)

This error in Orifice diameter of +20 % caused a positive bias in reported flow rate of +48.6 %. PROGNOSIS produced an alarm with the shortlist of possible causes including ‘Orifice diameter entered falsely high’.

d) Incorrectly entered Orifice diameter, d = 50.13 mm

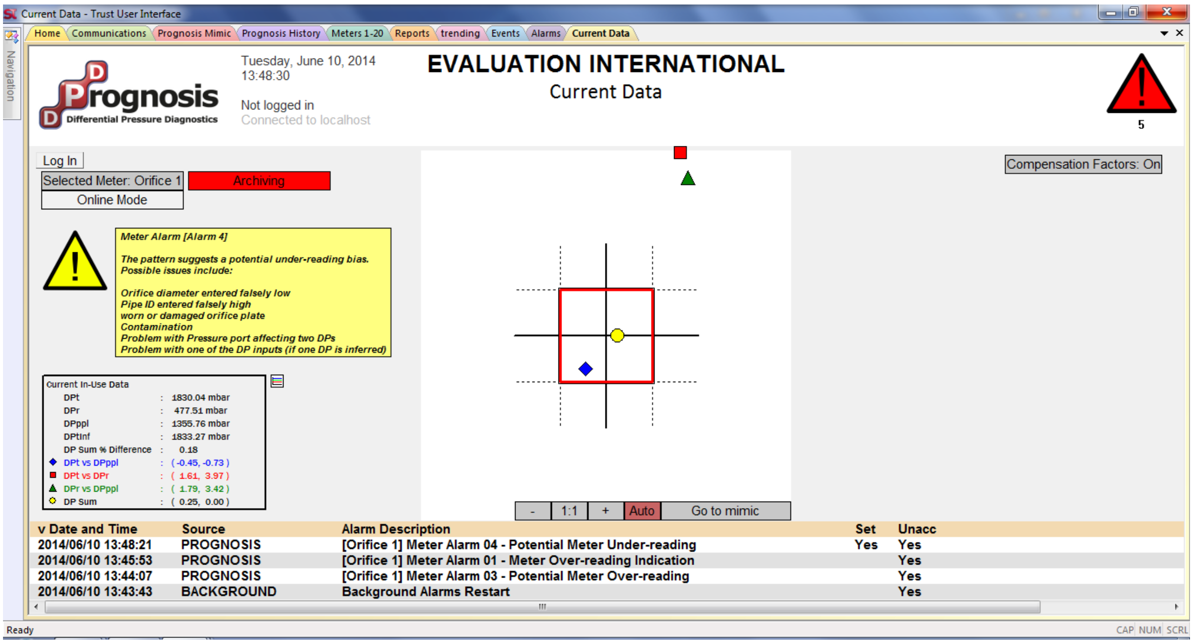


Figure 40 – Snapshot for the test with the incorrectly entered Orifice diameter (D = 50.13 mm)

This error in Orifice diameter of -2 % caused a negative bias in reported flow rate of -4.2 %. PROGNOSIS produced an alarm with the shortlist of possible causes including 'Orifice diameter entered falsely low'.

e) Incorrectly entered Orifice diameter, d = 41.13 mm

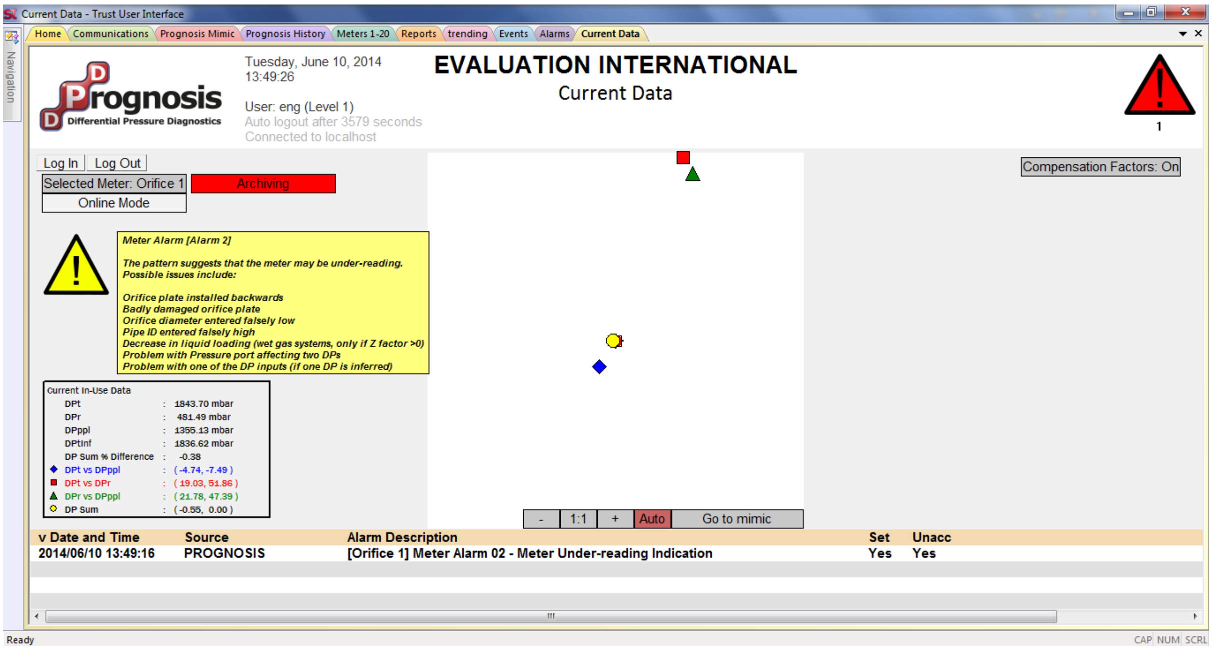


Figure 41 – Snapshot for the test with the incorrectly entered Orifice diameter (D = 41.13 mm)

This error in Orifice diameter of -19.6 % caused a negative bias in reported flow rate of -36.8 %. PROGNOSIS produced an alarm with the shortlist of possible causes including 'Orifice diameter entered falsely low'.

Result: In each test case PROGNOSIS provided a shortlist of ‘possible causes’ including the ‘right error indication’, that means: ‘Orifice diameter entered falsely high’ or ‘Orifice diameter entered falsely low’.

4.4. Test 4 – Influence of an incorrect set discharge coefficient (C_d) value

Objective – determine whether the DUT detects that the discharge coefficient was changed.
Criteria – DUT should react in accordance with the manufacturers' specifications.

a) *Incorrect discharge coefficient in use,* $C_d = 0.608$
b) *Incorrect discharge coefficient in use,* $C_d = 0.615$
c) *Incorrect discharge coefficient in use,* $C_d = 0.625$

This test was an attempt to simulate an error in calculated discharge coefficient for example if PROGNOSIS were to use a ‘keypad’ discharge coefficient or a discharge coefficient from an external source (e.g., flow computer) rather than calculate internally and iteratively around Reynolds Number and Mass Flow. To simulate this error, the discharge coefficient was set to ‘keypad mode’ in the PROGNOSIS user interface. The tests were carried out at Reynolds number of approximately 400000, at a temperature of 30 ˚C and at a pressure of 4.4 barG.

The correctly calculated discharge coefficient was approximately 0.6046.

a) Incorrect discharge coefficient in use, C_d = 0.608

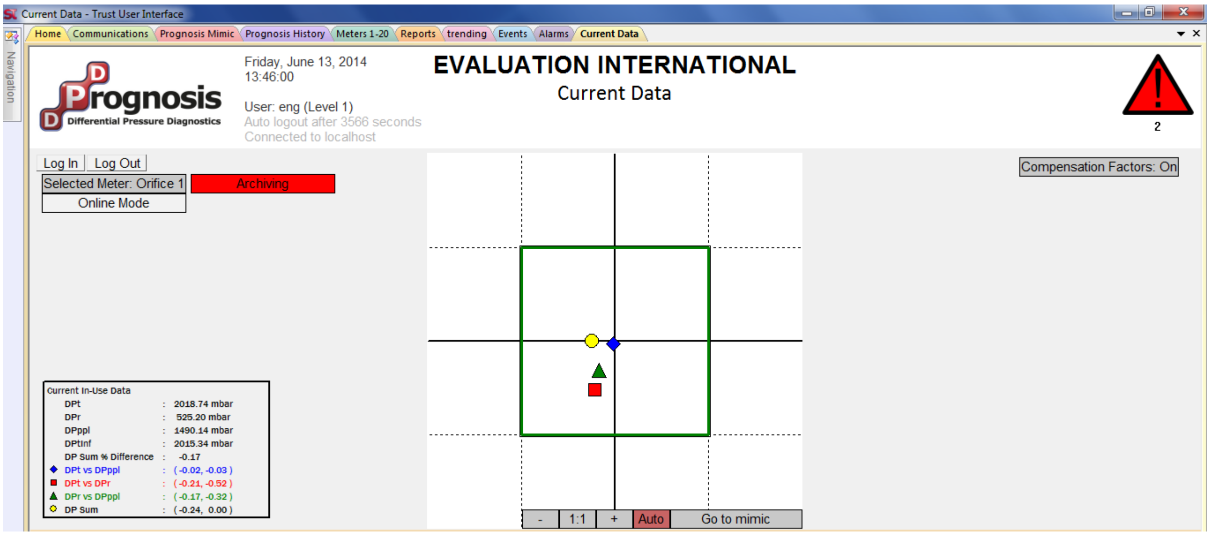


Figure 42 – Snapshot for the test with the incorrect discharge coefficient (C_d = 0.608) (infrequent alarm – 1/2)

This error in Cd of +0.5 % also caused a flow rate prediction bias of +0.5 %. Although a ‘shift’ in diagnostic response was observed, this was not significant enough to raise a permanent alarm in PROGNOSIS although an alarm was raised for 10 seconds out of 104 as shown in the second screen grab below.

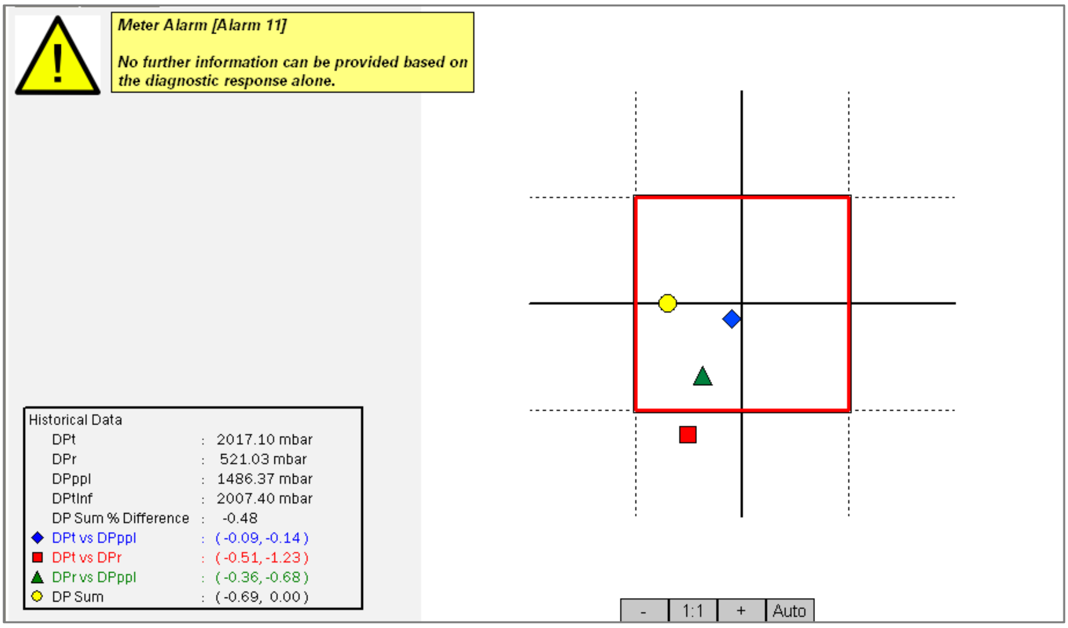


Figure 43 – Snapshot for the test with the incorrect discharge coefficient (C_d = 0.608) (infrequent alarm – 2/2)

The diagnostic response is as expected; there is no significant error[5] in discharge coefficient (and hence no significant error in mass flow rate prediction) and so there is no PROGNOSIS alarm.

b) Incorrect discharge coefficient in use, C_d = 0.615

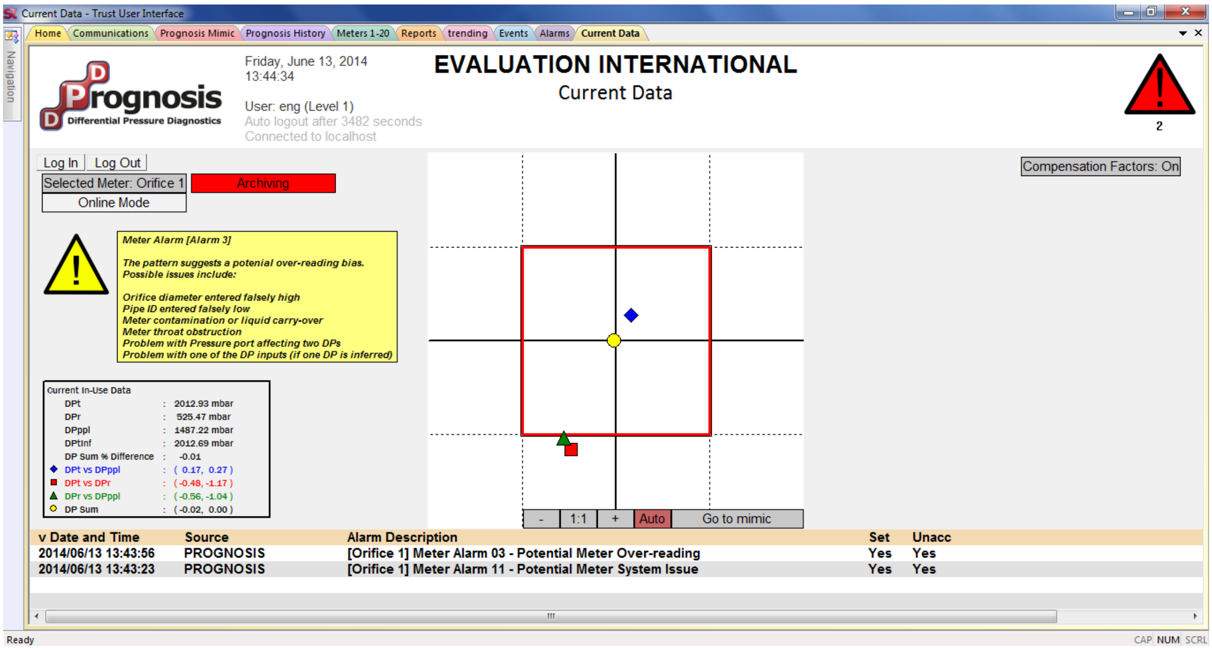


Figure 44 – Snapshot for the test with the incorrect discharge coefficient (C_d = 0.615)

This error in C_d of +1.7 % also caused a flow rate prediction bias of +1.7 %. This was a significant enough error to raise an alarm in PROGNOSIS.

---

[5] A 0.5% shift is e.g. significant to the buyers & sellers of natural gas. The appropriate definition is that an orifice C_d has 0.5% uncertainty, and the overall meter uncertainty is assumed to be 0.7%.The induced bias is smaller than the meter uncertainty, and that is defined here as 'not significant'.

c) Incorrect discharge coefficient in use, C_d = 0.625

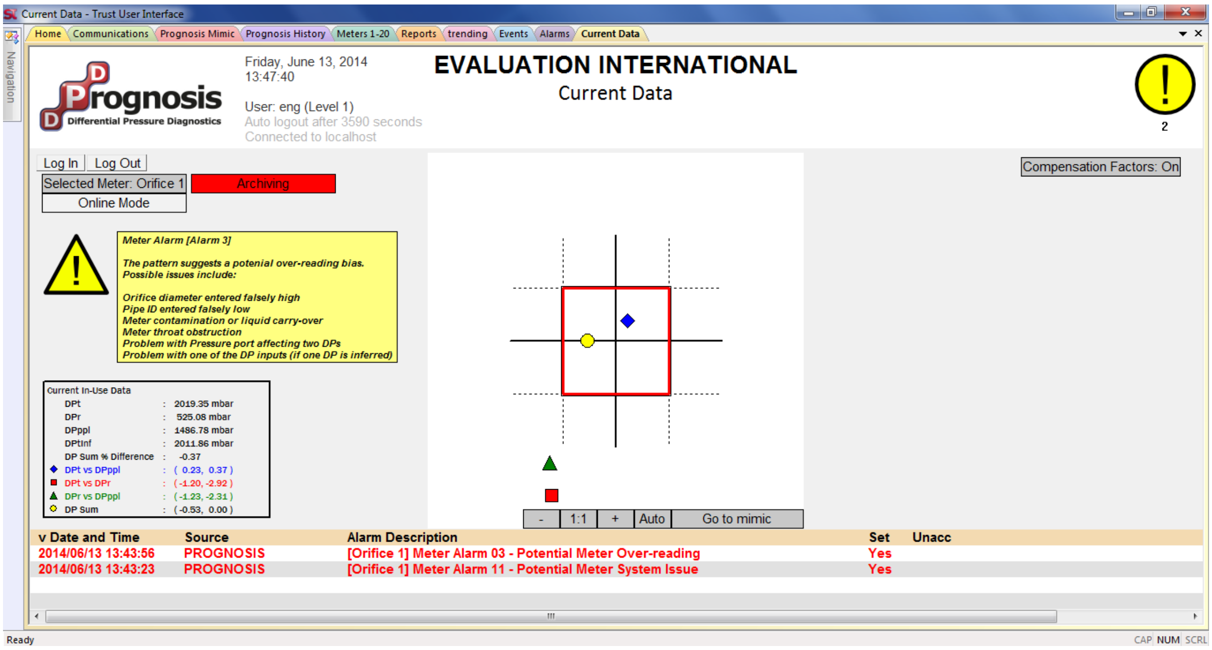


Figure 45 – Snapshot for the test with the incorrect discharge coefficient (C_d = 0.625)

This error in C_d of +3.4 % also caused a flow rate prediction bias of +3.4 %. PROGNOSIS raised an alarm.

<u>Result:</u> The test result shows that PROGNOSIS gives an alarm if the discharge coefficient will be changed.

<u>NOTE:</u> For Orifice plate flow meters, it is expected that the discharge coefficient will be calculated within PROGNOSIS and not acquired externally, hence there is no mention of a potential error in discharge coefficient in the shortlist of 'possible causes' of the alarm.

4.5. Test 5 – Influence of a blocked impulse (pressure) line(s)

Objective – determine whether the DUT detects that a DP-transmitter impulse line is blocked.
Criteria – DUT should react in accordance with the manufacturers' specifications.

The impulse pressure line was blocked at Hi-side then at Lo-side on each DP-transmitter in turn.

a) *DPt Hi pressure line blocked (Re = 400 000 at a temperature of 40 ˚C)*
b) *DPt Lo pressure line blocked (Re = 400 000 at a temperature of 40 ˚C)*
c) *DPr Hi pressure line blocked (Re = 400 000 at a temperature of 40 ˚C)*
d) *DPr Lo pressure line blocked (Re = 400 000 at a temperature of 40 ˚C)*
e) *DPppl Hi pressure line blocked (Re = 400 000 at a temperature of 40 ˚C)*
f) *DPppl Lo pressure line blocked (Re = 400 000 at a temperature of 40 ˚C)*

Note: During some of these tests the flow rate was not changed therefore in these tests the pressure in the affected port was fixed at the time the port was blocked. Any resulting error in DP measurement is a result of fluctuating flow at the same controlled flow rate. In all cases, the PROGNOSIS system provides an indication of the error in DP measurement by using the trusted measurement of the other two DPs (refer to Section 2.2 equation (1).

a) **DPt Hi pressure line blocked**

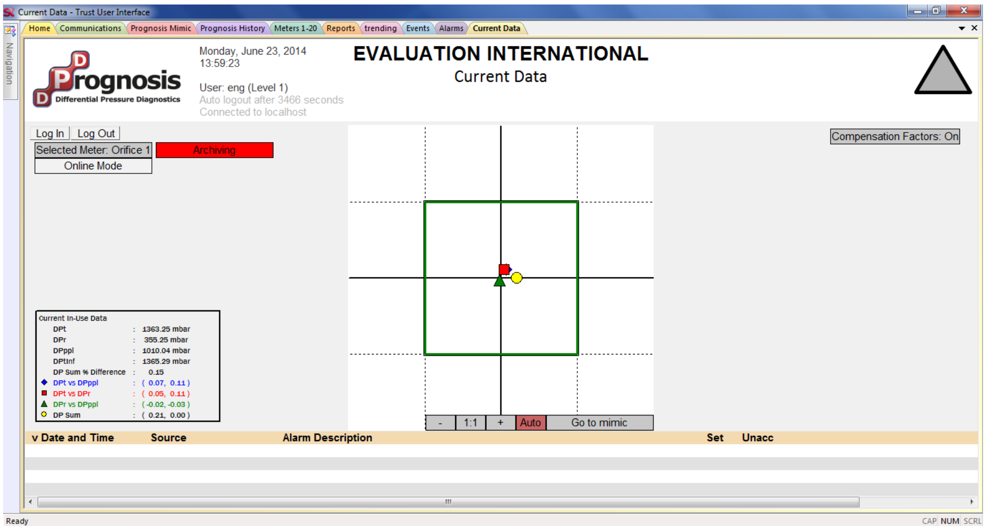


Figure 46 – Snapshot for the starting situation: unblocked pressure line (DPt Hi-side)

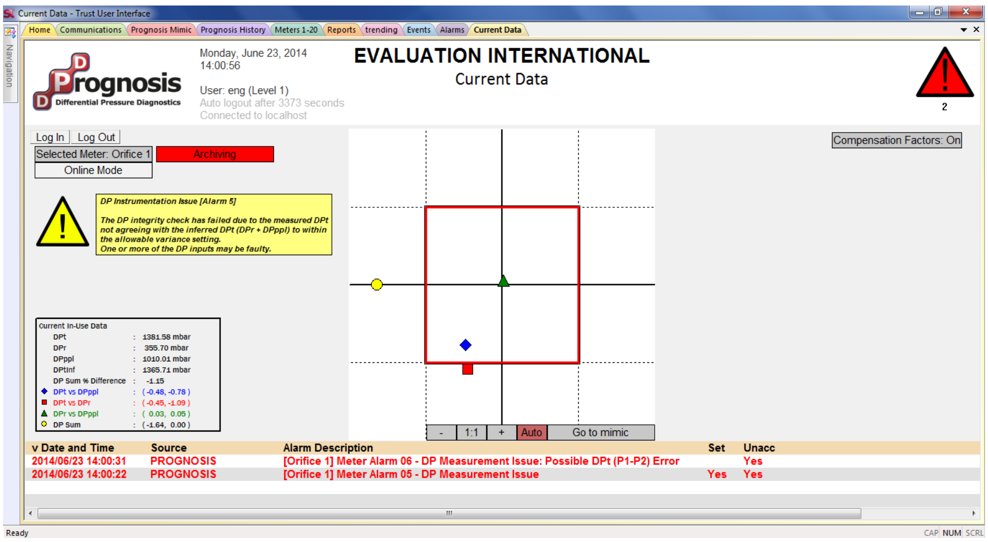


Figure 47 – Snapshot for test with a blocked DP-transmitter pressure line (DPt Hi-side)

As can be seen in Figure 47, PROGNOSIS raised an alarm intermittently (not continuously). ROGNOSIS only raised an alarm when the DPt changed significantly from the time the port was blocked. The alarm raised clearly indicated a DP integrity issue and often correctly indicated which DP the error was with (i.e., the DPt).

Using the example captured in Figure 47, assuming that PROGNOSIS displays the difference in measured from inferred DPt which in this case is -1.15 %.
Assuming that the DPr and DPppl measurements are accurate, the actual DPt is 1365.71 mbar whereas reported DPt is 1381.58 mbar which is in error by +1.16 %. The associated flow rate prediction error was estimated to be just +0.58 % and PROGNOSIS was still sensitive to this.

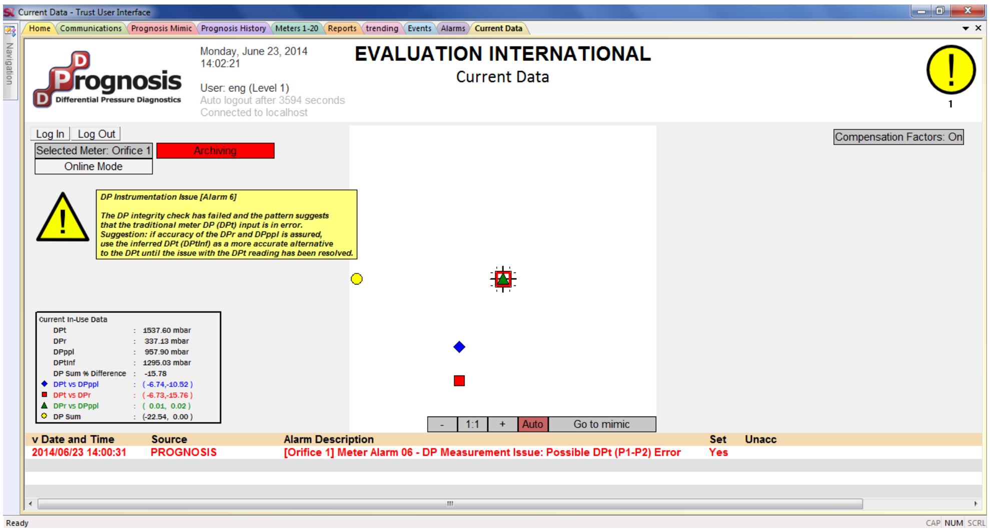


Figure 48 – Snapshot for test with a blocked DP-transmitter pressure line and subsequent small decrease of the flow rate (DPt Hi-side)

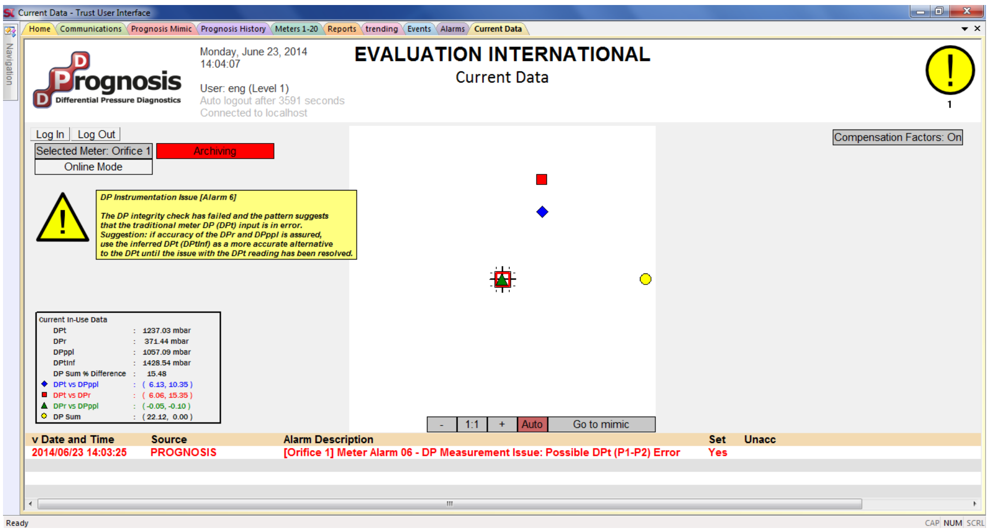


Figure 49 –Snapshot for test with a blocked DP-transmitter pressure line and subsequent small increase of the flow rate (DPt Hi-side)

This time the flow was changed hence the DPt had changed significantly (as indicated by the 'DP Sum % Difference' displayed by the PROGNOSIS software) from the time the pressure port was blocked. Hence PROGNOSIS detected an issue with the DPt and raised the corresponding alarm.

b) DPt Lo pressure line blocked

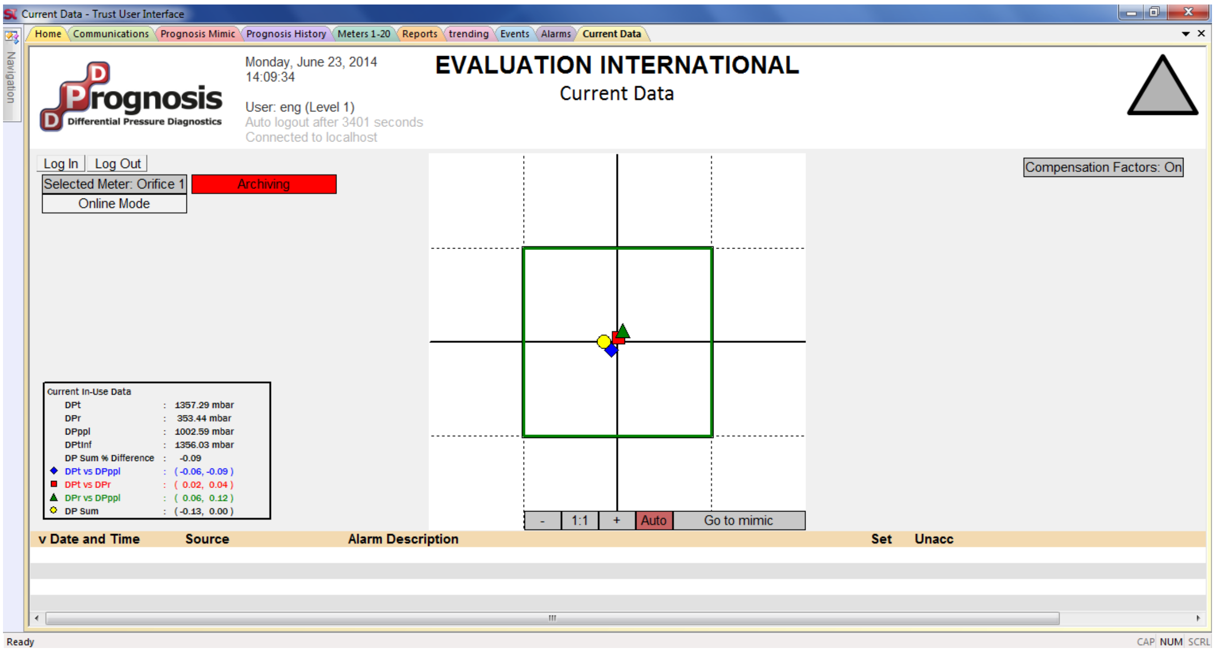


Figure 50 – Snapshot for the starting situation: unblocked pressure line (DPt Lo-side)

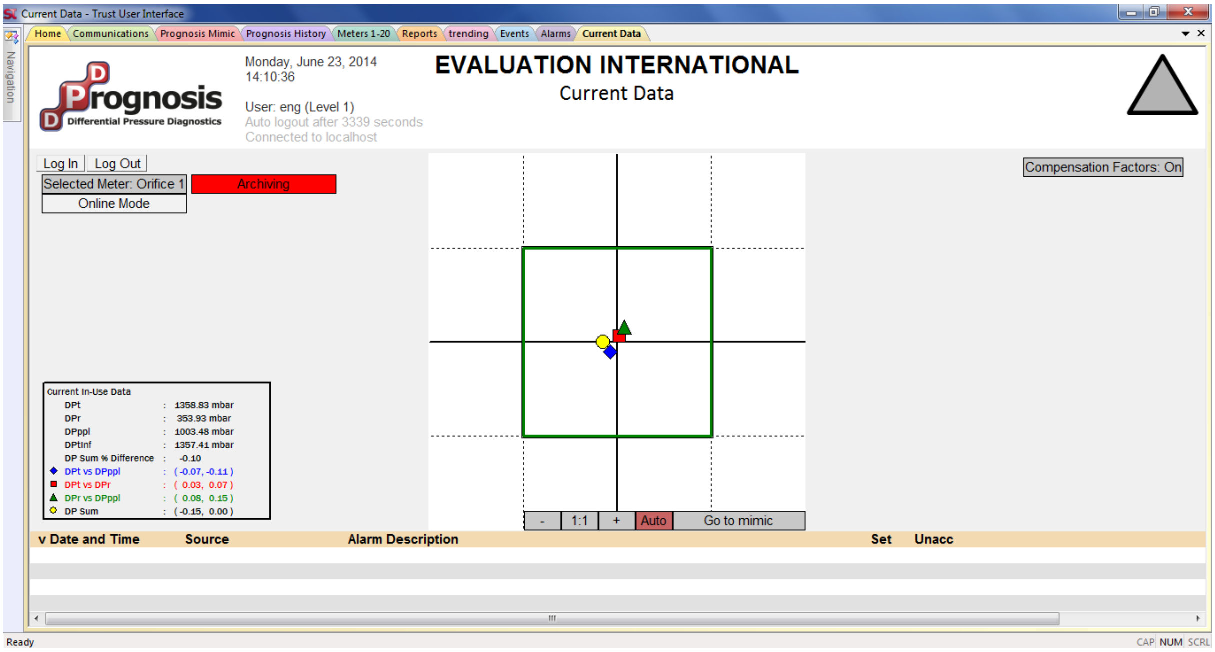


Figure 51 – Snapshot for test with a blocked DP-transmitter pressure line (DPt Lo-side)

No significant change in flow hence no significant error in DP or in mass flow rate prediction and no PROGNOSIS alarm. Where PROGNOSIS raised an alarm intermittently it was due to natural fluctuations in flow/DP and hence due to a real error in the DPt reading caused by the blocked pressure port.

For this example the measured DPt is only 0.10 % different to the inferred DPt. Assuming that the inferred DPt is accurate (i.e., assuming that the measure DPr and DPppl are accurate) this results in just a +0.05% difference in flow rate prediction. In other words there is NO error in the reported flow rate, hence no alarm from PROGNOSIS.

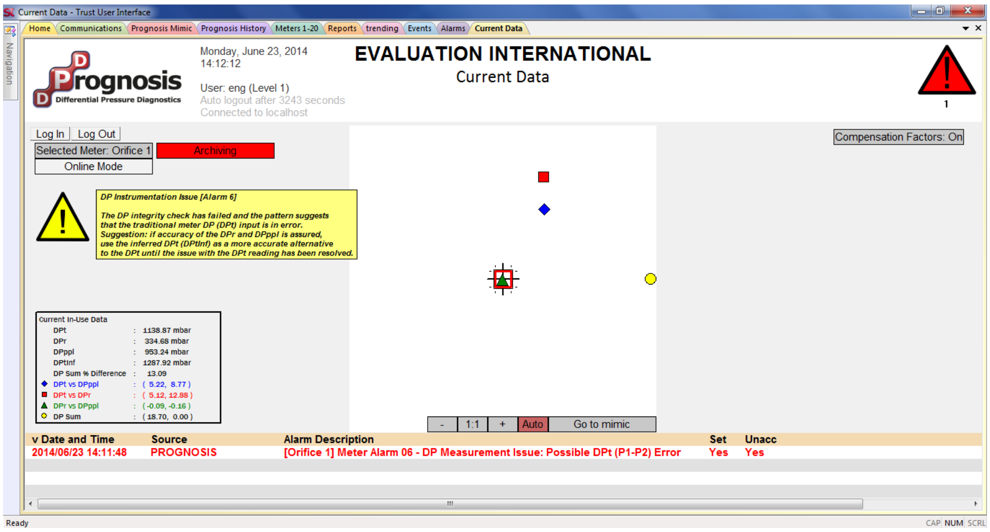


Figure 52 – Snapshot for test with a blocked DP-transmitter pressure line and subsequent small decrease of the flow rate (DPt Lo-side)

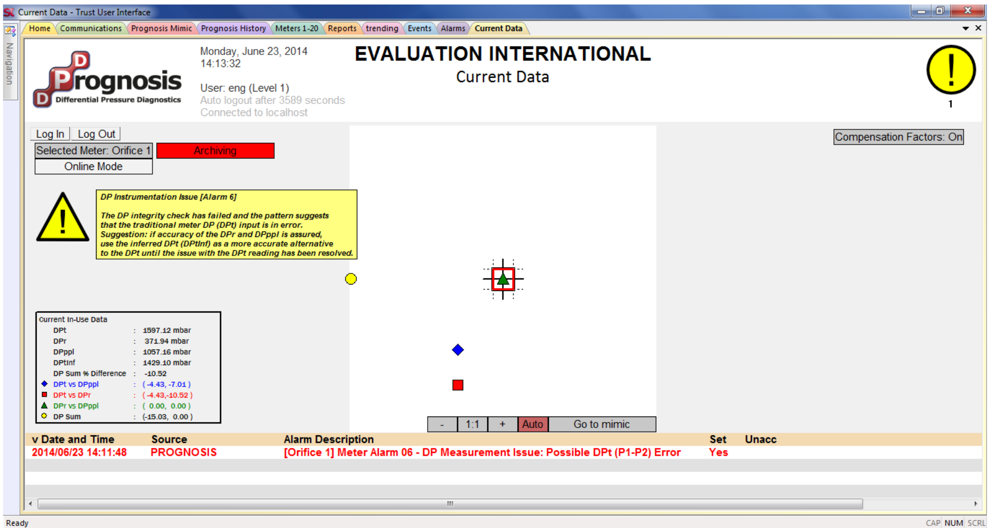


Figure 53 – Snapshot for test with a blocked DP-transmitter pressure line and subsequent small increase of the flow rate (DPt Lo-side)

This time the flow was changed hence the DPt had changed significantly (as indicated by the 'DP Sum % Difference' displayed by the PROGNOSIS software) from the time the pressure port was blocked. Hence PROGNOSIS detected an issue with the DPt and raised the corresponding alarm.

It can be seen here also that relatively steady flow conditions can lead to a situation where no alarm was caused over a long period of time.

c) DPr Hi pressure line blocked

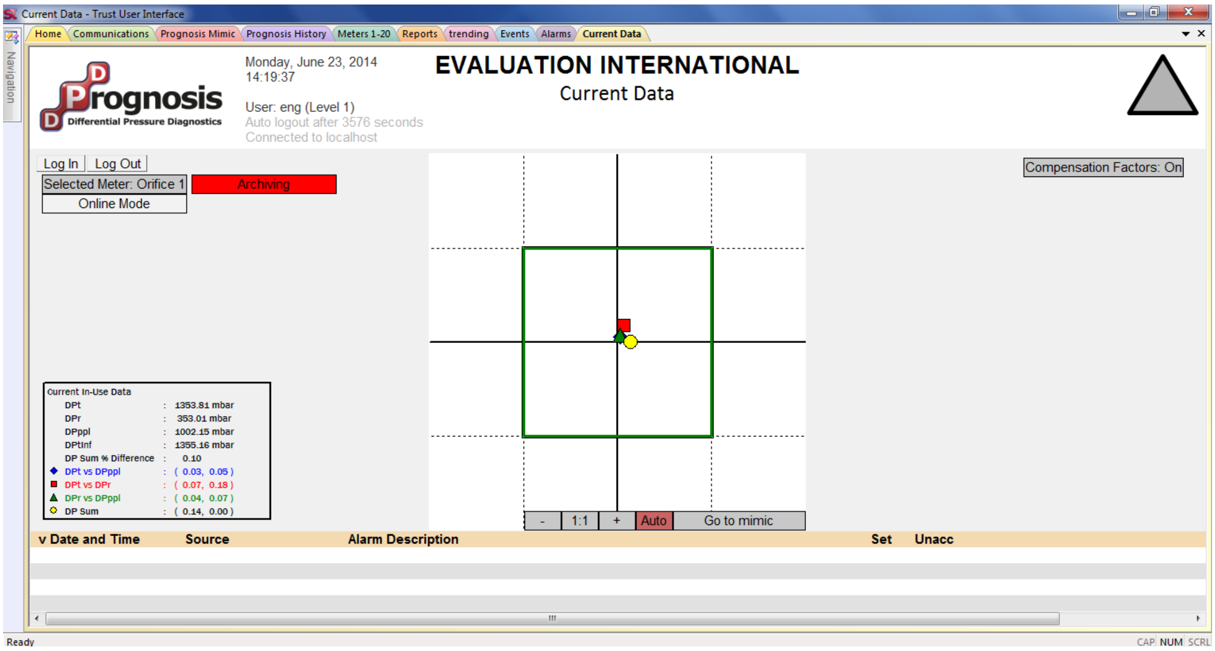


Figure 54 – Snapshot for the starting situation: unblocked pressure line (DPr Hi-side)

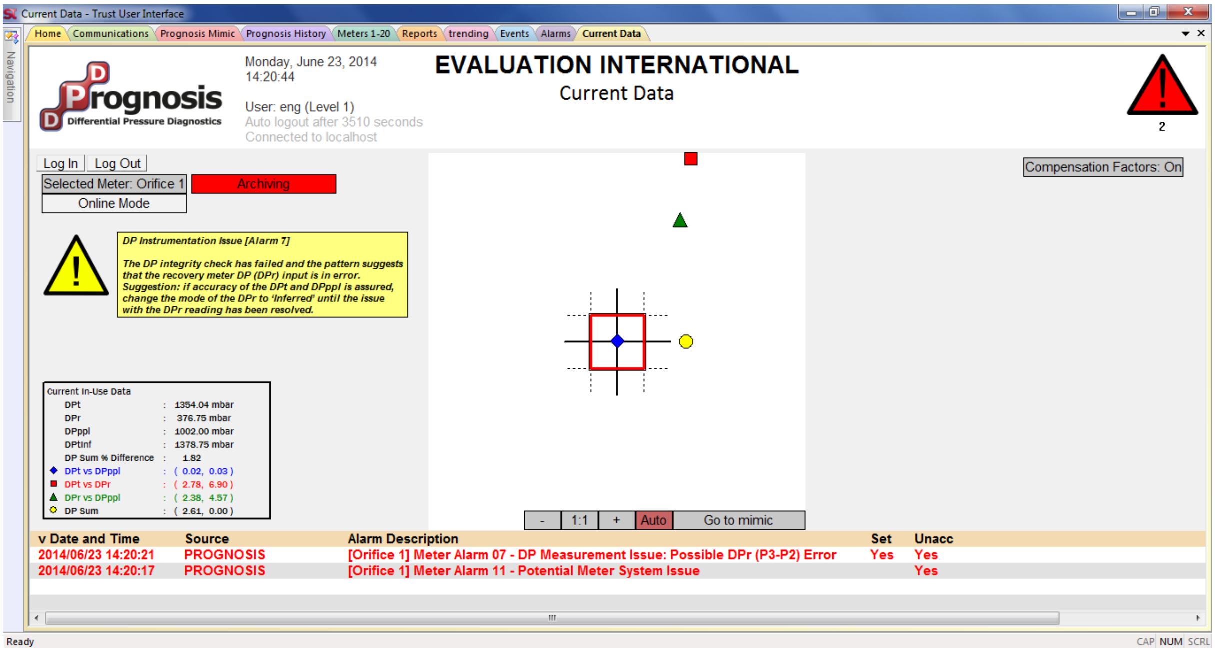


Figure 55 – Snapshot for test with a blocked DP-transmitter pressure line (DPr Hi-side)

PROGNOSIS raised an alarm indicating an integrity issue with the DPr. Even though an issue with the DPr would not affect the reported meter's 'traditional' flow rate prediction, this illustrates the fact that PROGNOSIS will 'self-diagnose' an issue with the diagnostic DPs.

Using the example captured in Figure 55, assuming that the DPt and DPppl measurements are accurate, the actual DPr is the difference between the two i.e., 1354.04 mbar – 1002.00 mbar = 352.04 mbar, the reported DPr is 367.75 mbar which is in error by +7.0 %.

d) DPr Lo pressure line blocked

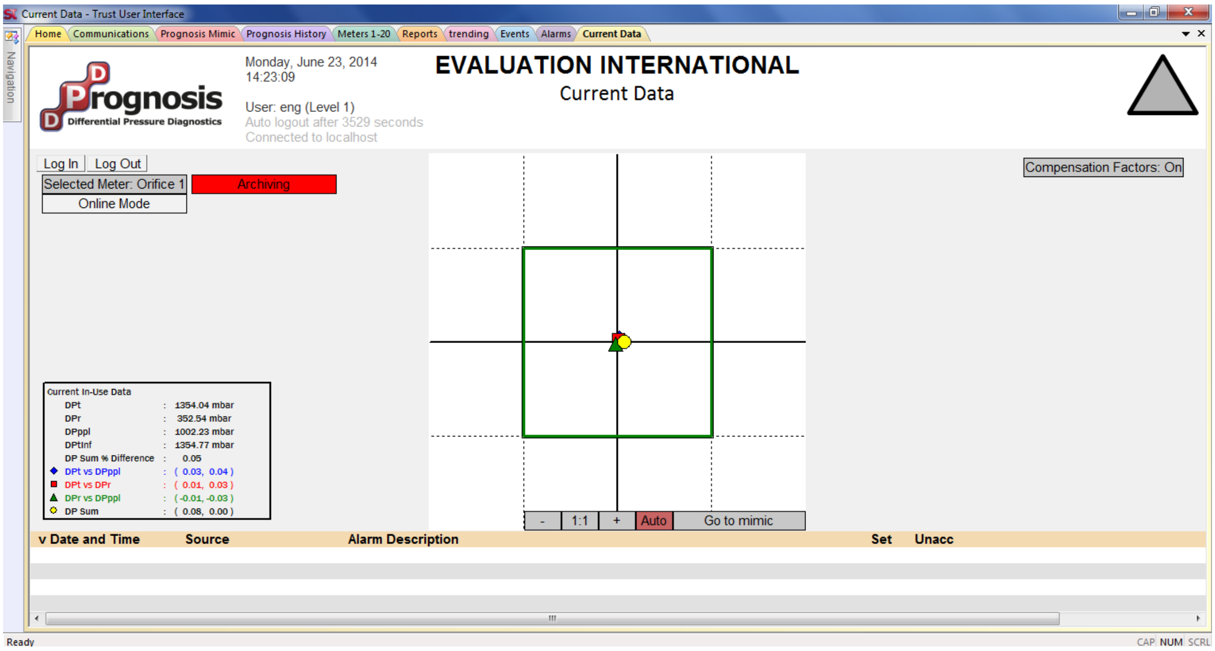


Figure 56 – Snapshot for the starting situation: unblocked pressure line (DPr Lo-side)

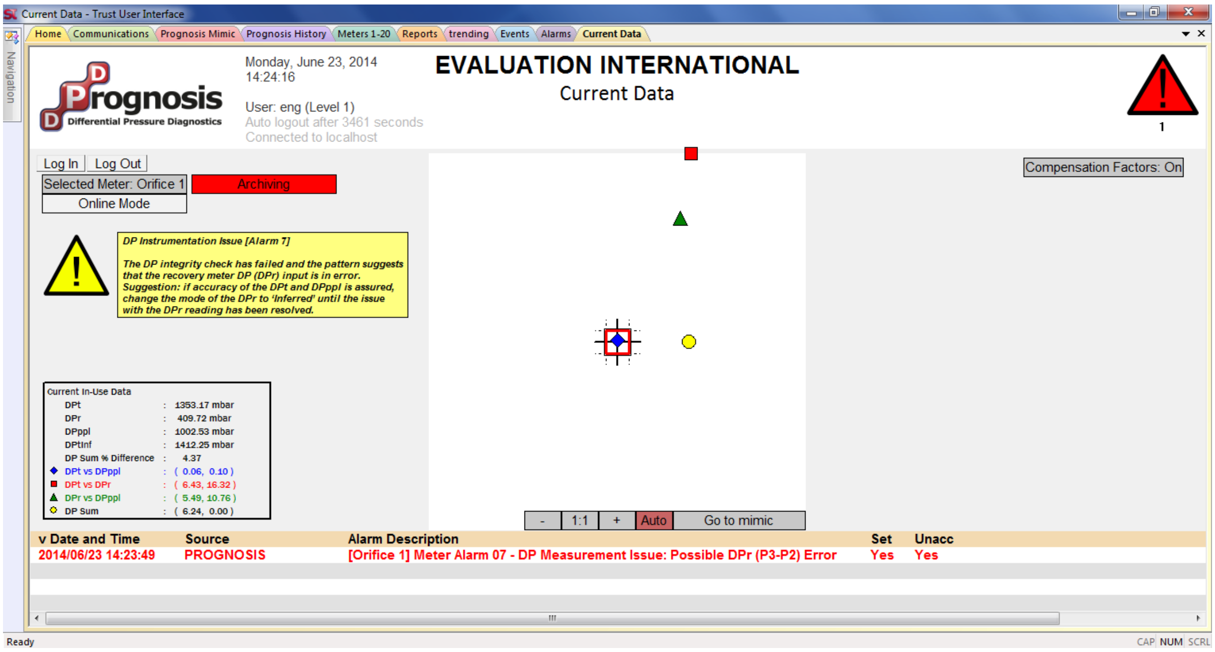


Figure 57 – Snapshot for test with a blocked DP-transmitter pressure line (DPr Lo-side)

The flow was fluctuating enough to significantly change the DPr and hence the blocked port produced an error in measured DPr and PROGNOSIS raised the associated alarm.

e) DPppl Hi pressure line blocked

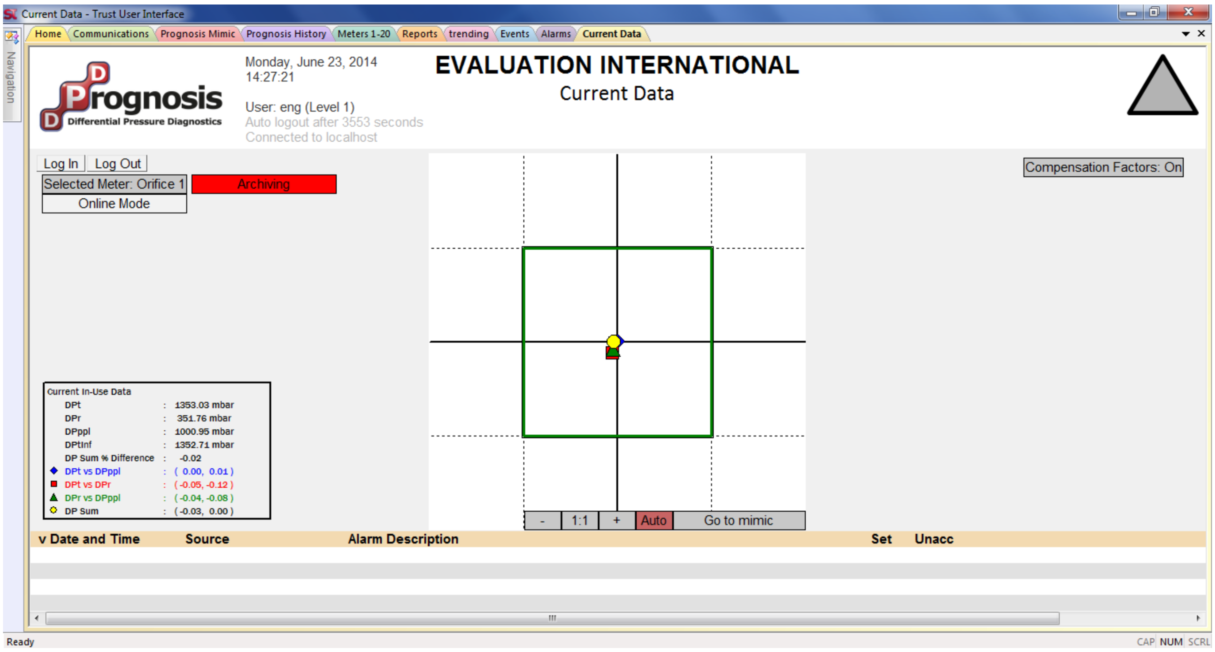


Figure 58 – Snapshot for the starting situation: unblocked pressure line (DPppl Hi-side)

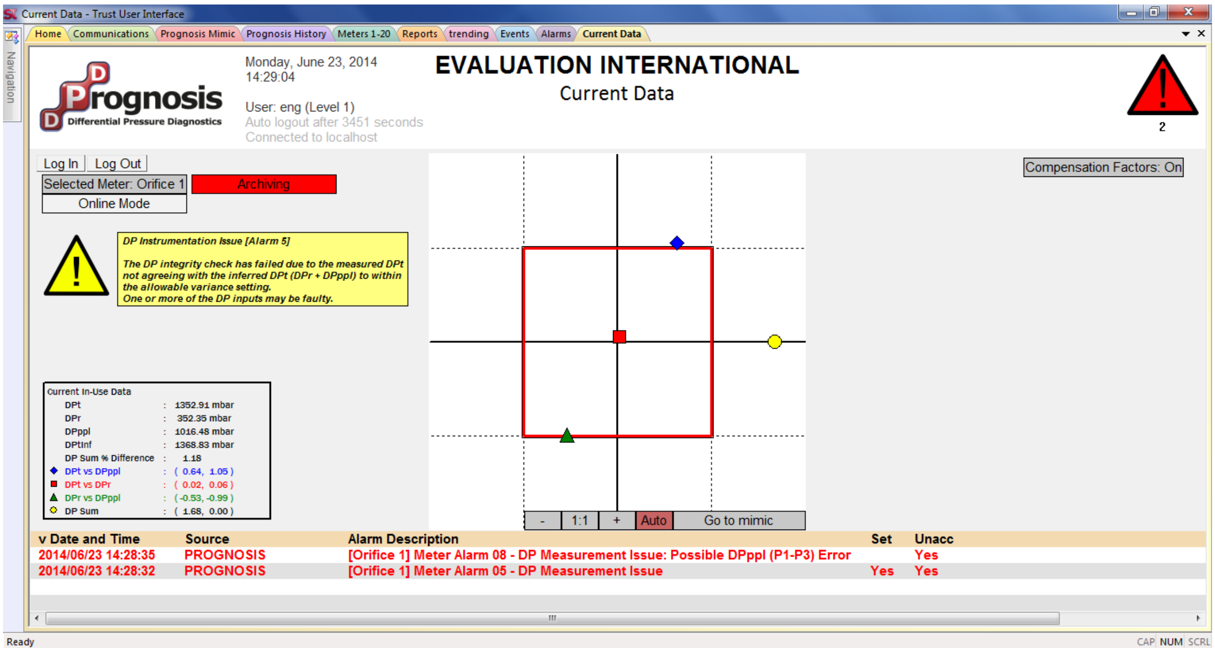


Figure 59 – Snapshot for test with a blocked DP-transmitter pressure line (DPppl Hi-side)

The flow was fluctuating enough to significantly change the DPppl and hence the blocked port produced an error in measured DPppl and PROGNOSIS raised the associated alarm.

PROGNOSIS raised an alarm indicating an integrity issue with the DPppl. Even though an issue with the DPppl would not affect the reported meter's 'traditional' flow rate prediction, this illustrates the fact that PROGNOSIS will 'self-diagnose' an issue with the diagnostic DPs.

Using the example captured in Figure 59, assuming that the DPt and DPr measurements are accurate, the actual DPppl is the difference between the two i.e., 1352.91 mbar – 352.35 mbar = 1000.56 mbar, the reported DPppl is 1016.48 mbar which is in error by +1.6 %.

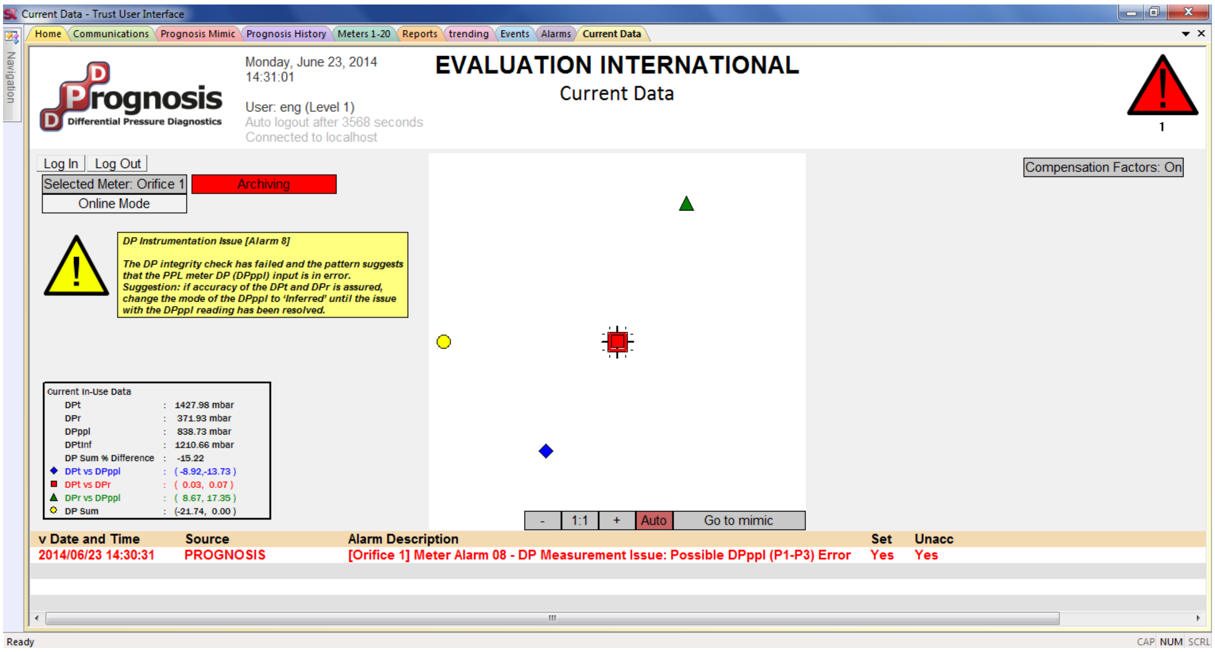


Figure 60 – Snapshot for test with a blocked DP-transmitter pressure line and subsequent small increase of the flow rate (DPppl Hi-side)

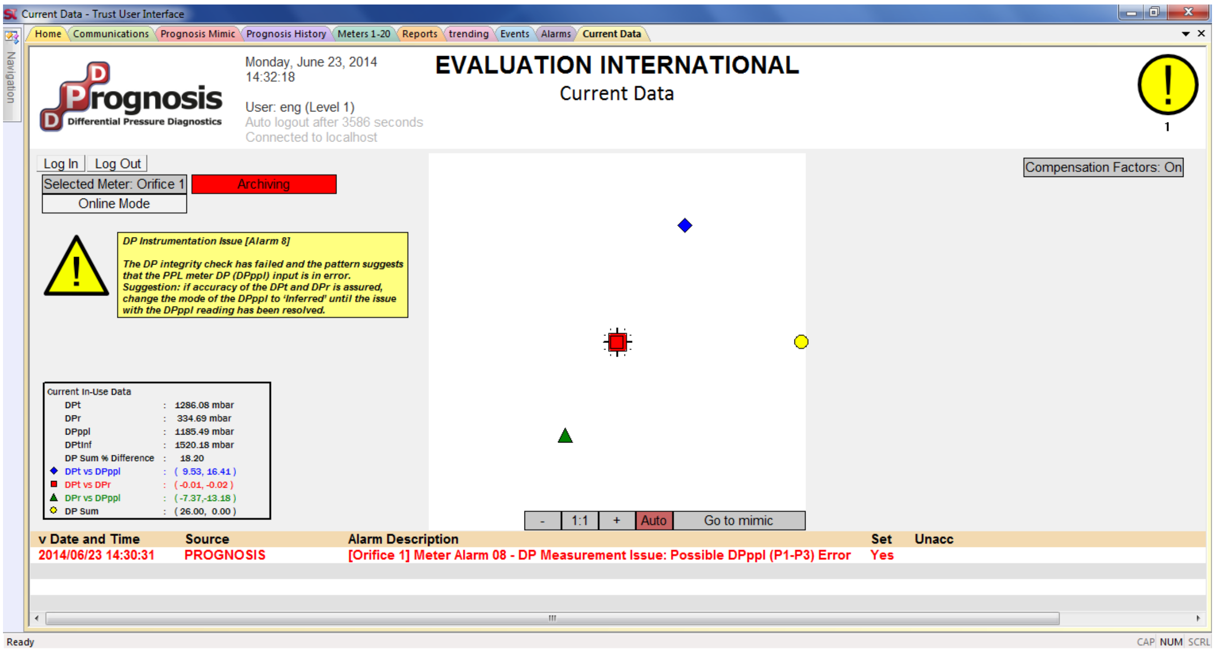


Figure 61 – Snapshot for test with a blocked DP-transmitter pressure line and subsequent small decrease of the flow rate (DPppl Hi-side)

Flow was changed hence the blocked port produced an incorrect DPppl measurement and a corresponding PROGNOSIS alarm.

f) DPppl Lo pressure line blocked

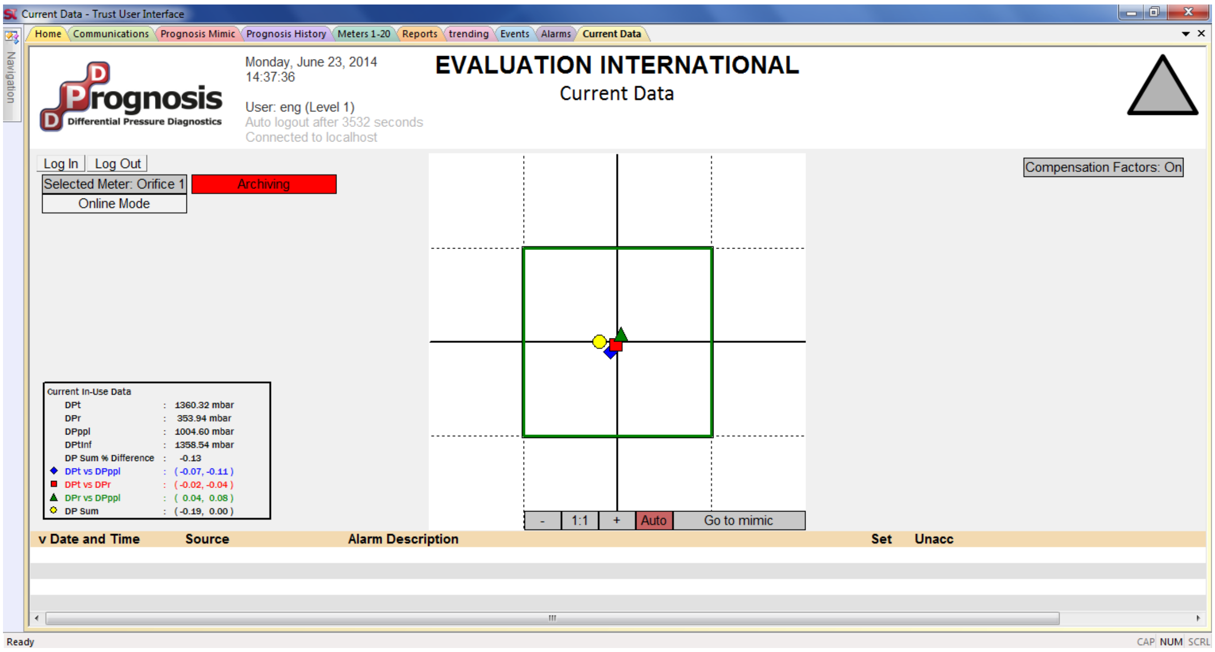


Figure 62 – Snapshot for the starting situation: unblocked pressure line (DPppl Lo-side)

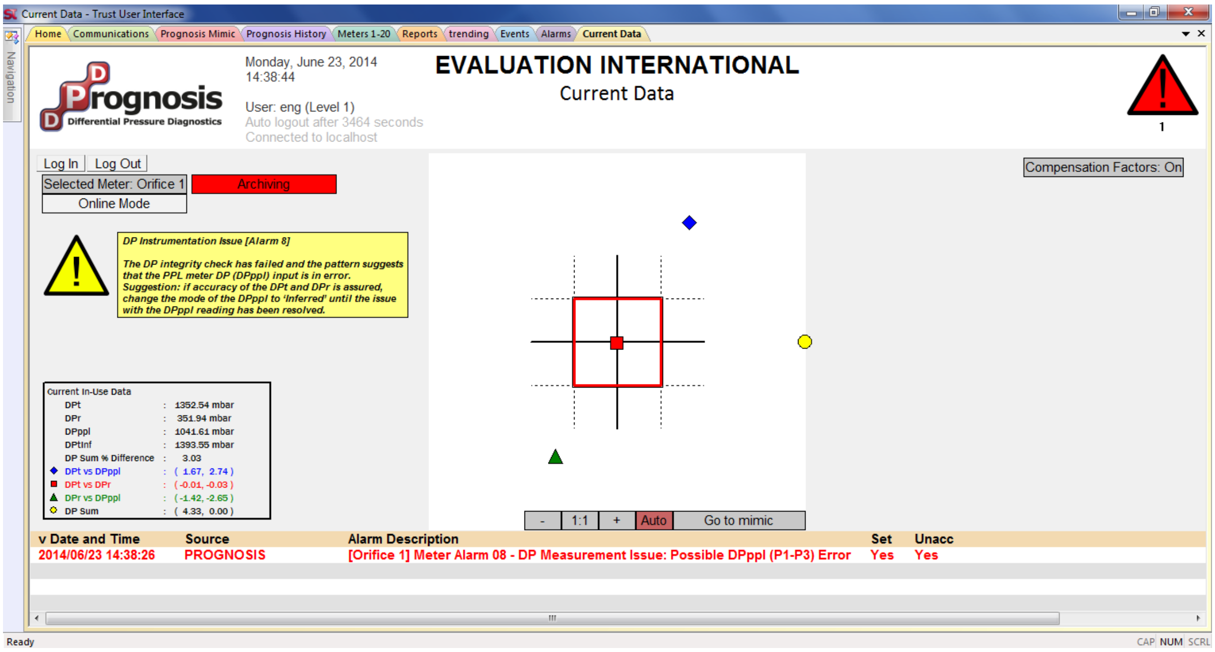


Figure 63 – Snapshot for test with a blocked DP-transmitter pressure line (DPppl Lo-side)

PROGNOSIS raised an alarm indicating an integrity issue with the DPppl. Even though an issue with the DPppl would not affect the reported meter's 'traditional' flow rate prediction, this illustrates the fact that PROGNOSIS will 'self-diagnose' an issue with the diagnostic DPs.

Using the example captured in Figure 63, assuming that the DPt and DPr measurements are accurate, the actual DPppl is the difference between the two i.e., 1352.54 mbar – 351.94 mbar = 1000.60 mbar, the reported DPppl is 1041.61 mbar which is in error by +4.1 %.

Result: Results were as expected with relatively steady flow; it is possible that there is no error induced by a blocked impulse line if the impulse line was blocked (especially for DPt) at the ‘correct’ pressure.

As flow conditions weren't changed during these tests the (fluctuating) diagnostic responses (alarms) were purely down to natural fluctuations in the flow rate and corresponding fluctuations in the DPs.
It was observed that there was more variation in the diagnostic response during these tests than with no blockage.

Since the errors were partially very low at steady state flow conditions (or not present at all at the ‘correct’ pressure) the flow rate was decreased and increased and additional tests were performed in order to carry out more industrially relevant tests.

4.6. Test 6 – Simulation of a leaking DP-transmitter equalisation valve

Objective – determine whether the DUT detects that a DP-transmitter equalisation valve is leaking.
Criteria – DUT should react in accordance with the manufacturers' specifications.

Equaliser valves were opened on each DP-transmitter in turn.

a) DPr equalisation valve open
b) DPppl equalisation valve open
c) DPt equalisation valve open

a) DPr equalisation valve open

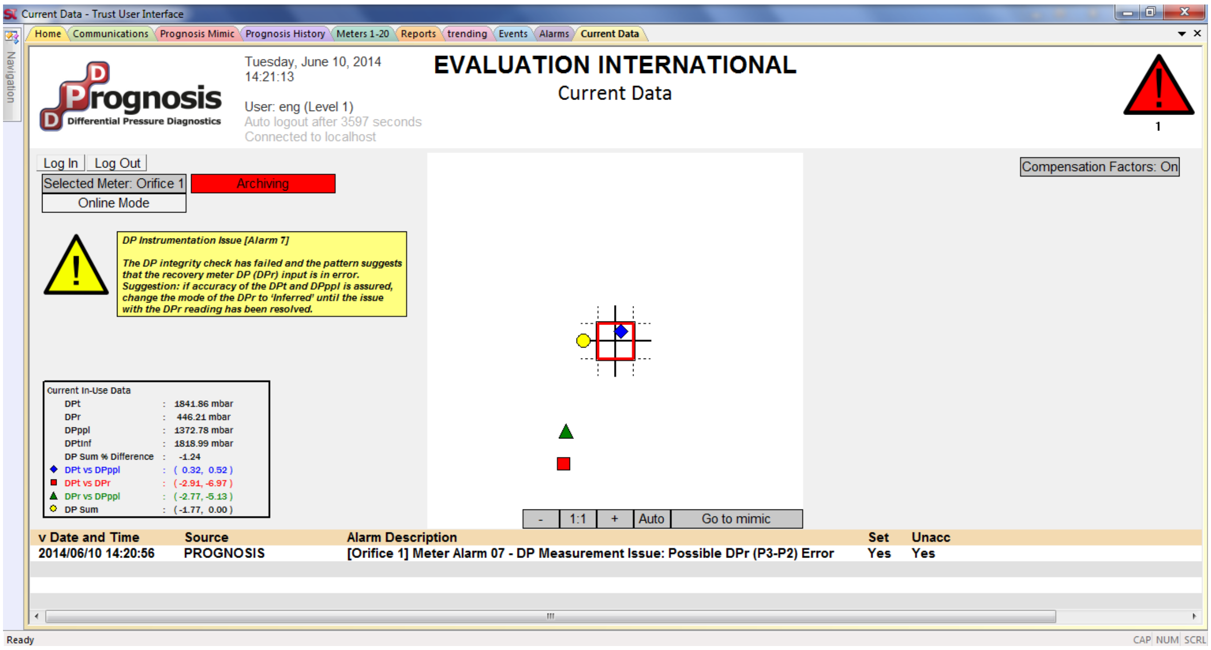


Figure 64 – Snapshot of the test with the open equalisation valve (DPr)

PROGNOSIS raises an alarm which clearly indicates an integrity issue with the DPr measurement. Even though an issue with the DPr would not affect the reported meter’s ‘traditional’ (DPt) flow rate prediction, this illustrates the fact that PROGNOSIS will ‘self-diagnose’ an issue with the diagnostic DPs.
Using this example and assuming that the DPt and DPppl measurements are accurate, the actual DPr is the difference between the two i.e., 1841.86 mbar – 1372.78 mbar = 469.08 mbar, the reported DPr is 446.21 mbar which is in error by -4.9 %.

b) DPppl equalisation valve open

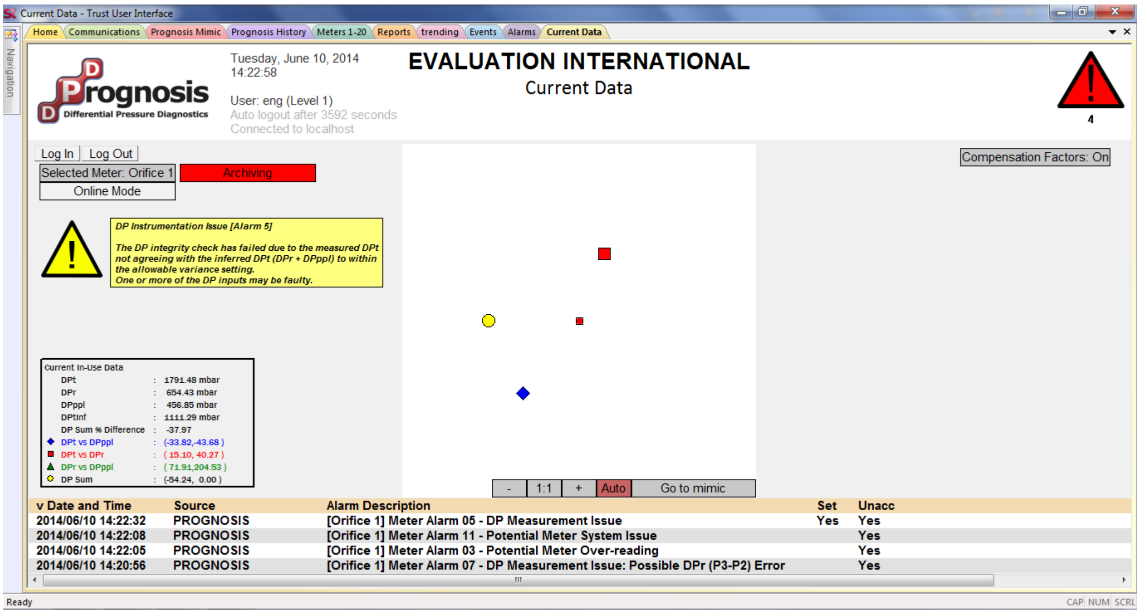


Figure 65 – Snapshot of the test with the open equalisation valve (DPppl)

PROGNOSIS raises an alarm which clearly indicates a DP integrity issue.
Using this example and assuming that the DPt and DPr measurements are accurate, the actual DPppl is the difference between the two i.e., 1791.48 mbar – 654.43 mbar = 1137.05 mbar, the reported DPppl is 456.85 mbar which is in error by -59.8%. This gross error causes all 4 points to lie far away from the origin with the 'DPr vs DPppl' point (green triangle) falling outside of the visible plot.

c) DPt equalisation valve open

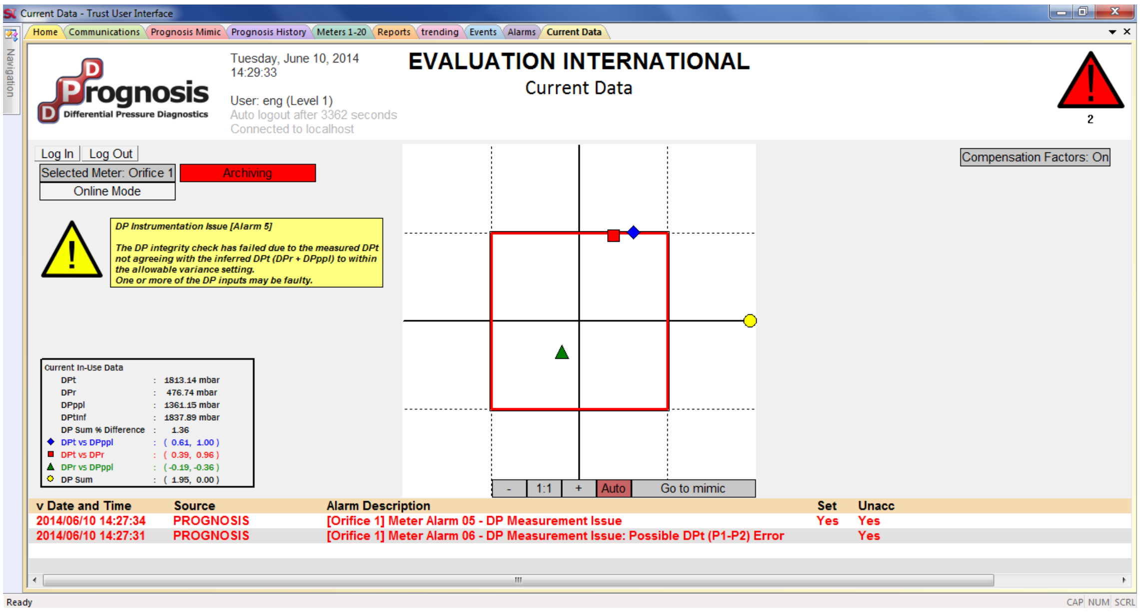


Figure 66 – Snapshot of the test with the open equalisation valve (DPt)

PROGNOSIS clearly indicates a DP integrity issue (i.e. specifically with the DP sum yellow point) and the 'DPr vs DPppl' point (green triangle) remaining close to the origin further indicates that the issue is with the DPt measurement. Assuming that the inferred DPt is accurate, the measured DPt is low by -1.35 %. The resulting flow rate prediction error is just -0.67 %. PROGNOSIS clearly raises an alarm.

Result: In each test case PROGNOSIS correctly indicated a ‘DP instrumentation issue’ due to the DP integrity check failing. In addition, the alarm raised by PROGNOSIS correctly identified which DP-transmitter was in error (in each case the DP identified was that with the equalisation valve open).

4.7. Test 7 – Influence of an incorrectly working DP-transmitter

Objective – determine whether the DUT detects that a DP-transmitter is working incorrectly.
Criteria – DUT should react in accordance with the manufacturers' specifications.

a) DPr raw mA value changed from approximately 11.6 to 12.6 mA
b) DPr raw mA value changed from approximately 11.6 to 10.6 mA
c) DPppl raw mA value changed from approximately 8.3 mA to 9.3 mA
d) DPppl raw mA value changed from approximately 8.3 mA to 7.3 mA
e) DPt raw mA value changed from approximately 9.9 mA to 10.9 mA
f) DPt raw mA value changed from approximately 9.9 mA to 8.9 mA

Simulation was used (current generator) to change the raw mA signal simulating and error in each DP measurement in turn.

The measured mA values were observed to be approximately: 9.9 mA for DPt, 11.6 mA for DPr and 8.3 mA for DPppl.

a) DPr raw mA value changed from approximately 11.6 to 12.6 mA

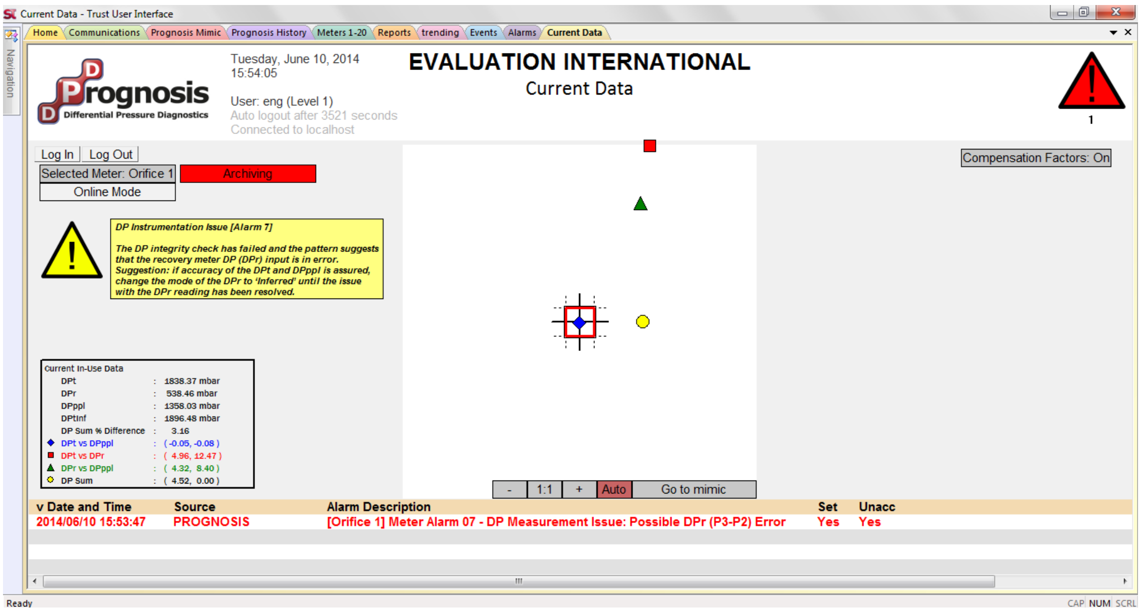


Figure 67 – Snapshot of the DP-transmitter test (DPr current signal increased by 1.0 mA)

PROGNOSIS raises an alarm which clearly indicates an integrity issue with the DPr measurement. Even though an issue with the DPr would not affect the reported meter’s ‘traditional’ flow rate prediction, this illustrates the fact that PROGNOSIS will ‘self-diagnose’ an issue with the diagnostic DPs.
Using this example and assuming that the DPt and DPppl measurements are accurate, the actual DPr is the difference between the two i.e., 1838.37 mbar – 1358.03 mbar = 480.34 mbar, the reported DPr is 538.46 mbar which is in error by +12.1 %.

b) DPr raw mA value changed from approximately 11.6 to 10.6 mA

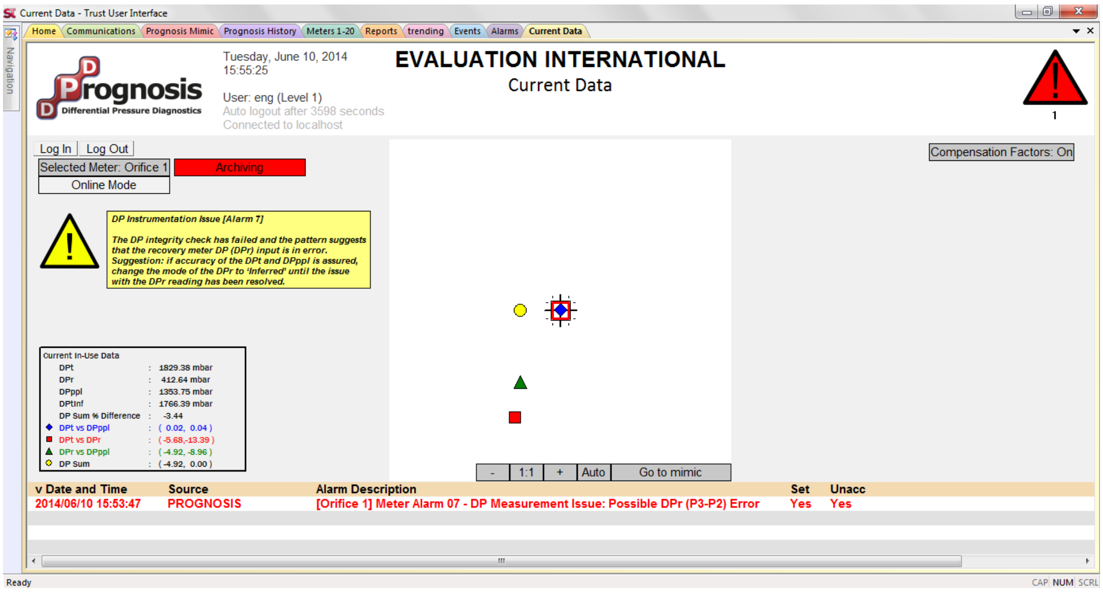


Figure 68 – Snapshot of the DP-transmitter test (DPr current signal decreased by 1.0 mA)

PROGNOSIS raises an alarm which clearly indicates an integrity issue with the DPr measurement. Even though an issue with the DPr would not affect the reported meter's 'traditional' flow rate prediction, this illustrates the fact that PROGNOSIS will 'self-diagnose' an issue with the diagnostic DPs.

Using this example and assuming that the DPt and DPppl measurements are accurate, the actual DPr is the difference between the two i.e., 1829.38 mbar – 1353.75 mbar = 475.63 mbar, the reported DPr is 412.64 mbar which is in error by -13.2 %.

c) DPppl raw mA value changed from approximately 8.3 mA to 9.3 mA

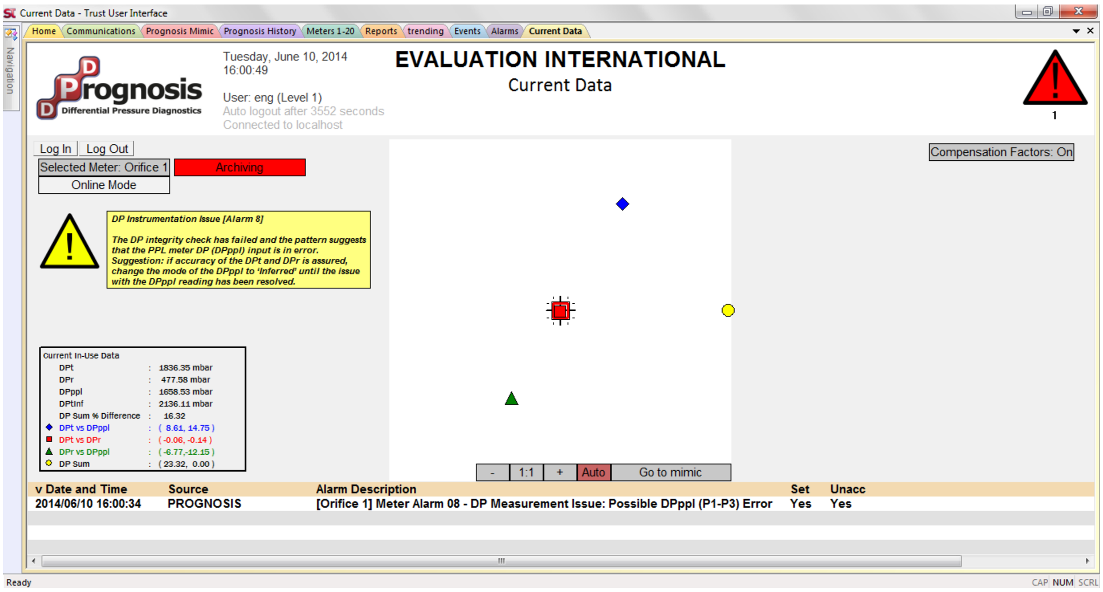


Figure 69 – Snapshot of the DP-transmitter test (DPppl current signal increased by 1.0 mA)

PROGNOSIS raises an alarm which clearly indicates an integrity issue with the DPppl measurement. Even though an issue with the DPppl would not affect the reported meter's 'traditional' flow rate prediction, this illustrates the fact that PROGNOSIS will 'self-diagnose' an issue with the diagnostic DPs.

Using this example and assuming that the DPt and DPr measurements are accurate, the actual DPppl is the difference between the two i.e., 1836.35 mbar – 477.58 mbar = 1358.77 mbar, the reported DPppl is 1658.53 mbar which is in error by +22.1 %.

d) DPppl raw mA value changed from approximately 8.3 mA to 7.3 mA

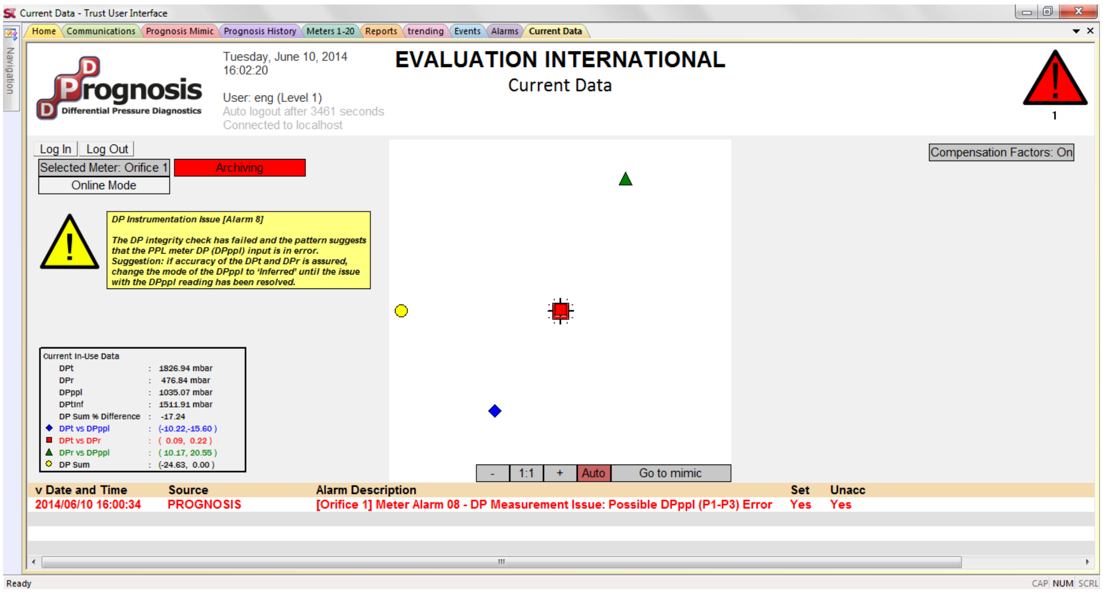


Figure 70 – Snapshot of the DP-transmitter test (DPppl current signal decreased by 1.0 mA)

PROGNOSIS raises an alarm which clearly indicates an integrity issue with the DPppl measurement. Even though an issue with the DPppl would not affect the reported meter's 'traditional' flow rate prediction, this illustrates the fact that PROGNOSIS will 'self-diagnose' an issue with the diagnostic DPs.

Using the example above, assuming that the DPt and DPr measurements are accurate, the actual DPppl is the difference between the two i.e., 1826.94 mbar – 476.84 mbar = 1350.10 mbar, the reported DPppl is 1035.07 mbar which is in error by -23.3 %.

e) DPt raw mA value changed from approximately 9.9 mA to 10.9 mA

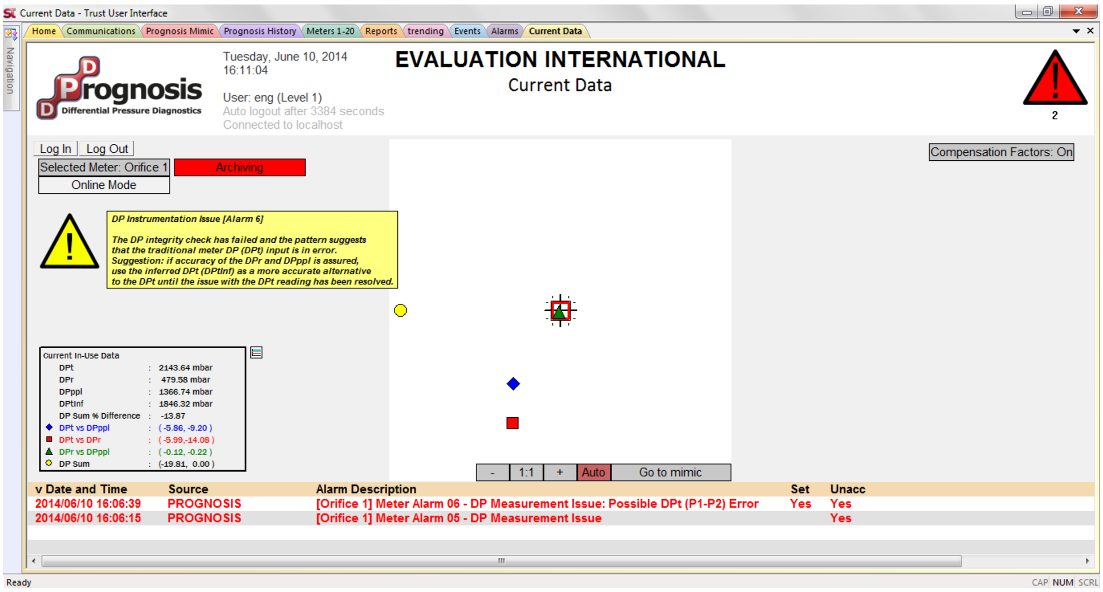


Figure 71 – Snapshot of the DP-transmitter test (DPt current signal increased by 1.0 mA)

PROGNOSIS raises an alarm which clearly indicates an integrity issue with the DPt measurement and hence with the resultant ‘traditional’ meter flow rate prediction.
Using the example above, assuming that the DPr and DPppl measurements are accurate, the actual DPt is the displayed ‘inferred DPt’ i.e., 1846.32 mbar, the reported DPt is 2143.64 mbar which is in error by +16.1 %. The resulting flow rate prediction has a bias of approximately +7.7 %.

f) DPt raw mA value changed from approximately 9.9 mA to 8.9 mA

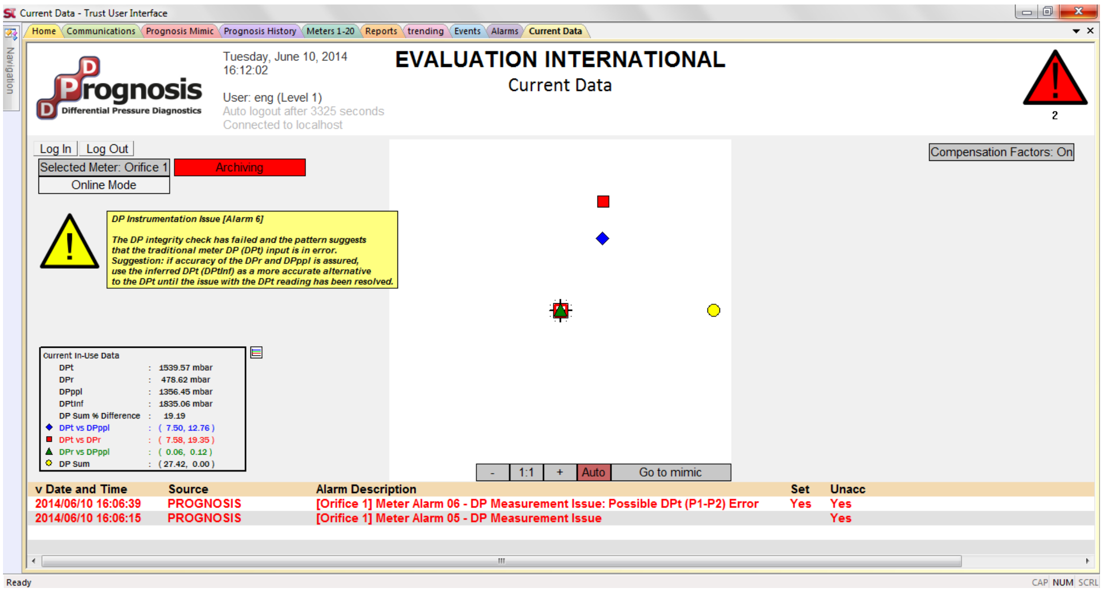


Figure 72 – Snapshot of the DP-transmitter test (DPt current signal decreased by 1.0 mA)

PROGNOSIS raises an alarm which clearly indicates an integrity issue with the DPt measurement and hence with the resultant ‘traditional’ meter flow rate prediction.
Using this example and assuming that the DPr and DPppl measurements are accurate, the actual DPt is the displayed ‘inferred DPt’ i.e., 1835.06 mbar, the reported DPt is 1539.57 mbar which is in error by -16.1 %. The resulting flow rate prediction has a bias of approximately -8.4 %.

Result: In each test case PROGNOSIS indicated a ‘DP instrumentation issue’ since the DP integrity check has failed for the (right) DP-transmitter where the current signal was changed.

4.8. Test 8 – Saturated DP-transmitter

Objective – determine whether the DUT detects that a DP-transmitter is saturated (blocked).
Criteria – DUT should react in accordance with the manufacturers' specifications.

a) *DPr will be fixed at a value slightly below the actual value*
b) *DPr will be fixed at a value below the actual value*

c) *DPppl will be fixed at a value below the actual value*

d) *DPt will be fixed at a value slightly below the actual value*
e) *DPt will be fixed at a value below the actual value*

Input value into PROGNOSIS was 'fixed' in the LabView program to simulate this error for each DP in turn. The correctly measured DPs were observed to be approximately **1746 mbar** (DPt), **455 mbar** (DPr) and **1290 mbar** (DPppl).

a) DPr fixed at 450 mbar

The two screens below show random diagnostic responses during this test with PROGNOSIS intermittently raising an alarm indicating a DP integrity issue.

Using the first example below, assuming that the DPt and the DPppl measurements are accurate, the actual DPr is approximately 459.61 mA (i.e., DPt – DPppl). Therefore the reported DPr of 450 mbar is in error by approximately -2.1 %.

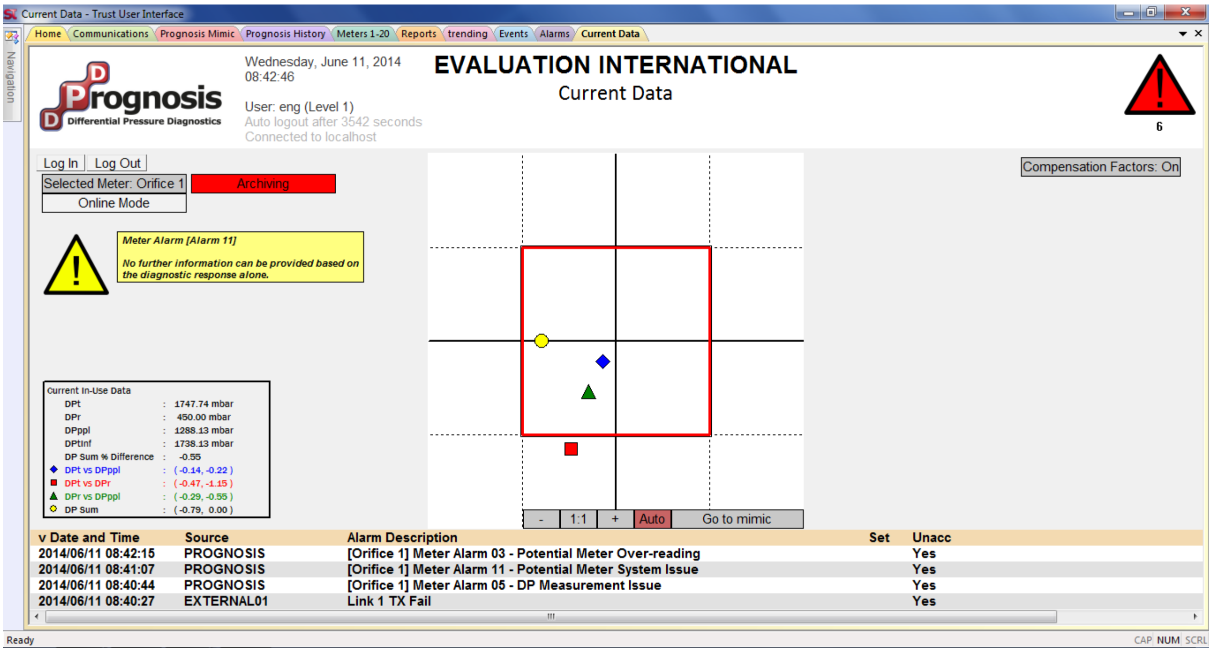


Figure 73 – Snapshot (1/2) of the test with the (simulated) saturated DP-transmitter (DPr fixed at 450 mbar)

Using the second example below, assuming that the DPt and the DPppl measurements are accurate, the actual DPr is approximately 471.8 mbar (i.e., DPt – DPppl). Therefore the reported DPr of 450 mbar is in error by approximately -4.6 %.

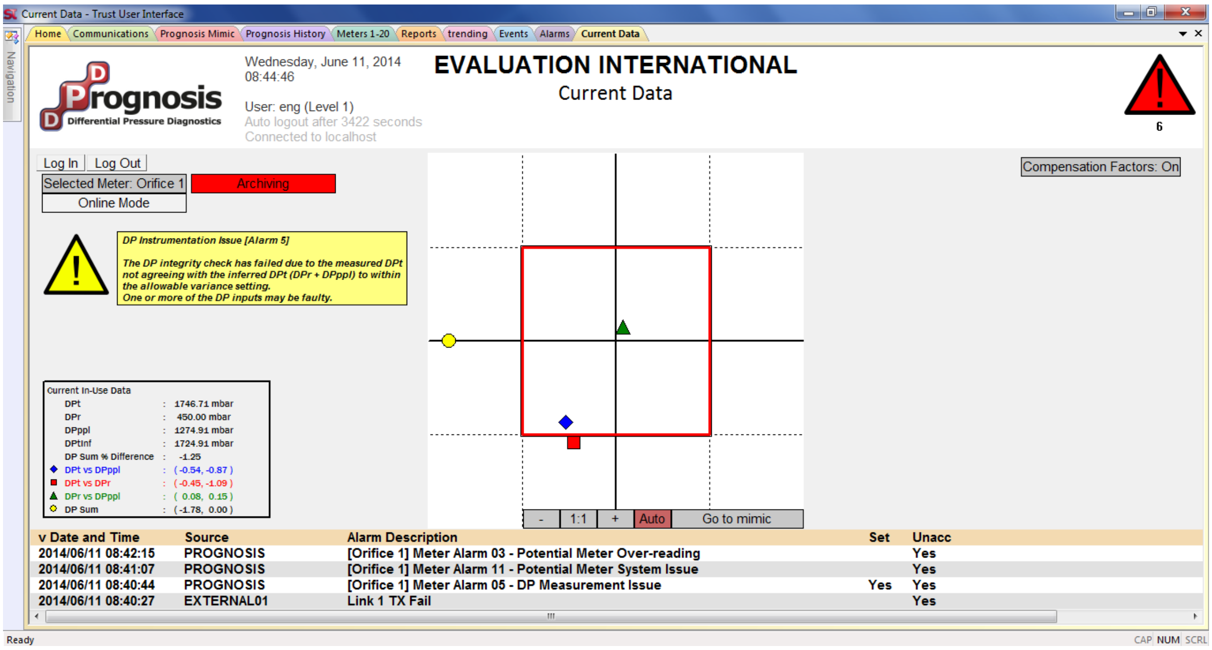


Figure 74 – Snapshot (2/2) of the test with the (simulated) saturated DP-transmitter (DPr fixed at 450 mbar)

b) DPr fixed at 400 mbar

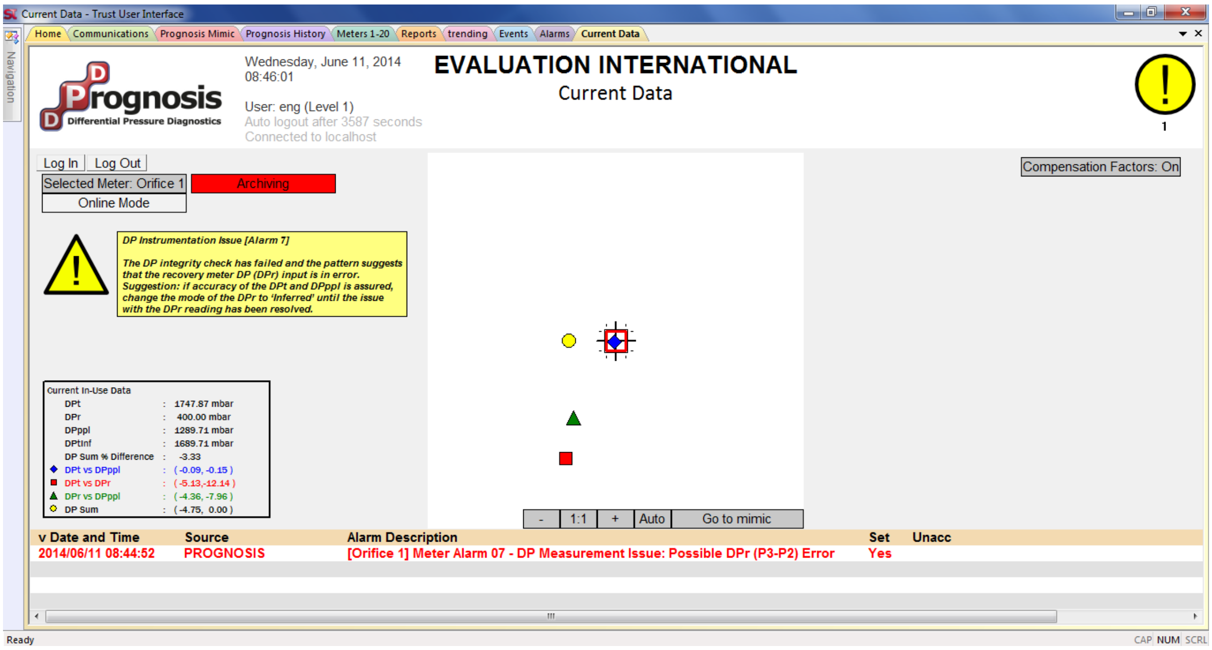


Figure 75 – Snapshot of the test with the (simulated) saturated DP-transmitter (DPr fixed at 400 mbar)

PROGNOSIS raises an alarm which clearly indicates an integrity issue with the DPr measurement. Using this example, assuming that the DPt and the DPppl measurements are accurate, the actual DPr is approximately 458.16 mbar (i.e., DPt – DPppl). Therefore the reported DPr of 400 mbar is in error by approximately -12.7 %.

c) DPppl fixed at 1250 mbar

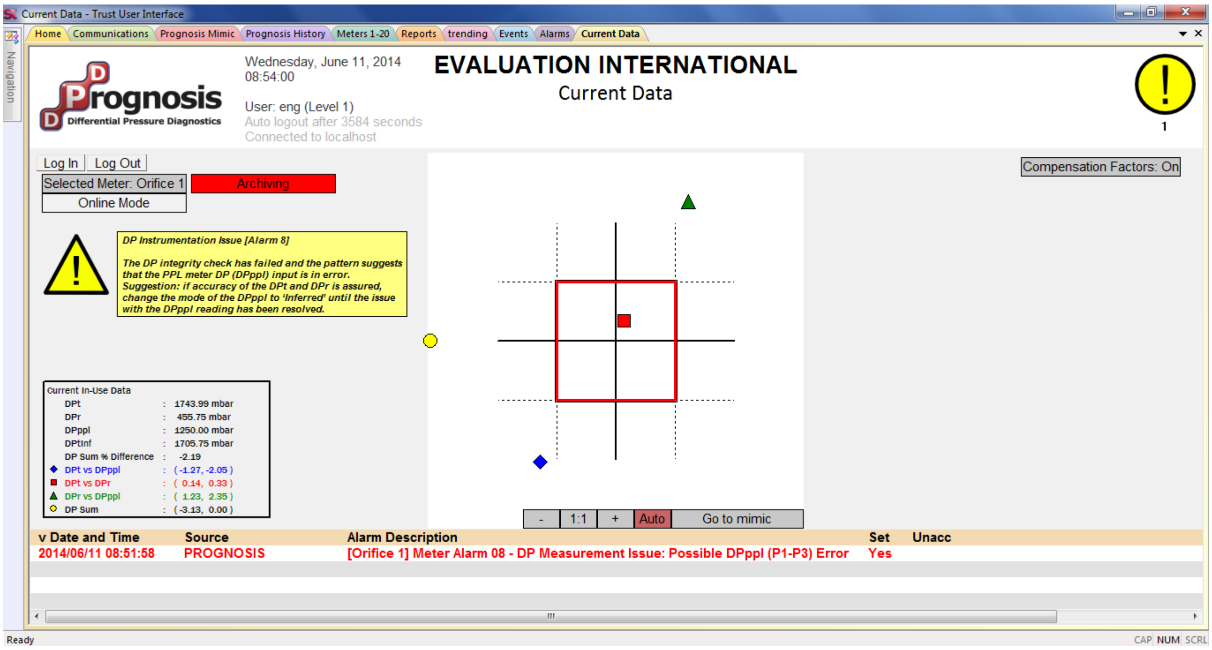


Figure 76 – Snapshot of the test with the (simulated) saturated DP-transmitter (DPppl fixed at 1250 mbar)

PROGNOSIS raises an alarm which clearly indicates an integrity issue with the DPppl measurement. Using this example, assuming that the DPt and the DPr measurements are accurate, the actual DPppl is approximately 1288.24 mbar (i.e., DPt – DPr). Therefore the reported DPppl of 1250 mbar is in error by approximately -3.0 %.

d) DPt fixed at 1740 mbar

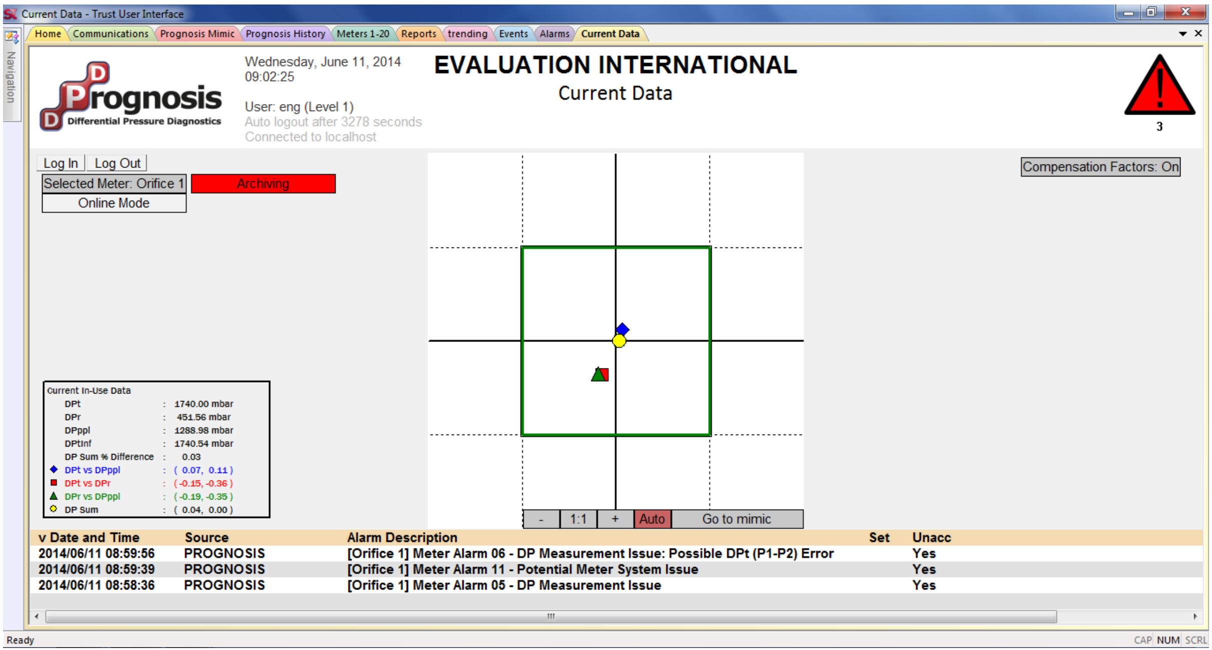


Figure 77 – Snapshot of the test with the (simulated) saturated DP-transmitter (DPt fixed at 1740 mA)

No significant error in DPt and hence no PROGNOSIS alarm is raised.
Using this example and assuming that the DPr and DPppl measurements are accurate, the actual DPt is 1740.54 mbar. There reported DPt is 1740 mbar hence there is no significant bias in reported flow rate prediction. (In this case it is only a -0.34 % DP-transmitter error, which results in a -0.17 % flow rate error.)

e) DPt fixed at 1720 mbar

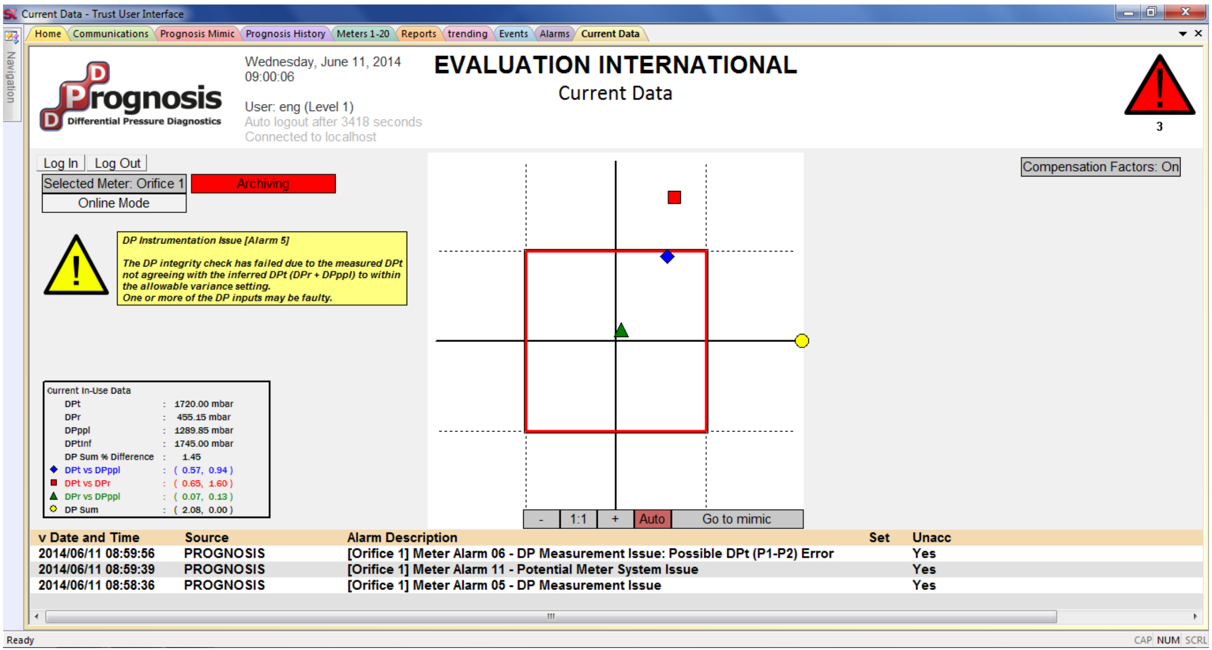


Figure 78 – Snapshot of the test with the (simulated) saturated DP-transmitter (DPt fixed at 1720 mbar)

PROGNOSIS clearly raises an alarm indicating an error in reported DPt (and hence in the reported flow rate prediction).
Using this example and assuming that the DPr and DPppl measurements are accurate, the actual DPt is 1745.00 mbar. There reported DPt is 1720 mbar which is in error by approximately -1.4 %; the resulting flow rate prediction has a bias of approximately -0.7 %.

<u>Result:</u> In each test case PROGNOSIS indicated a ‘DP instrumentation issue’ since the DP integrity check has failed for the (right) DP-transmitter where the pressure value was fixed.

4.9. Test 9 – Drifting DP-transmitter

This test was not performed as considered covered by tests 7, 8 and 10.

4.10. Test 10 – DP-transmitter range incorrectly entered

Objective – determine whether the DUT detects that the range of a DP-transmitter is incorrectly set (‘over-ranged’).
Criteria – DUT should react in accordance with the manufacturers' specifications.

a) DPr incorrectly ranged (‘over-ranged’)
b) DPppl incorrectly ranged (‘over-ranged’)
c) DPt incorrectly ranged (‘over-ranged’)

<u>DP-transmitter working range:</u>

- 3.2 mA (‚failure, alarm‘) – 3.6 mA – 21.6 mA (‚over-ranged‘)

Issue was simulated in the LabView program for each transmitter in turn.

a) DPr incorrectly ranged - causing DPr to read approximately 1108 mbar (21.6 mA)

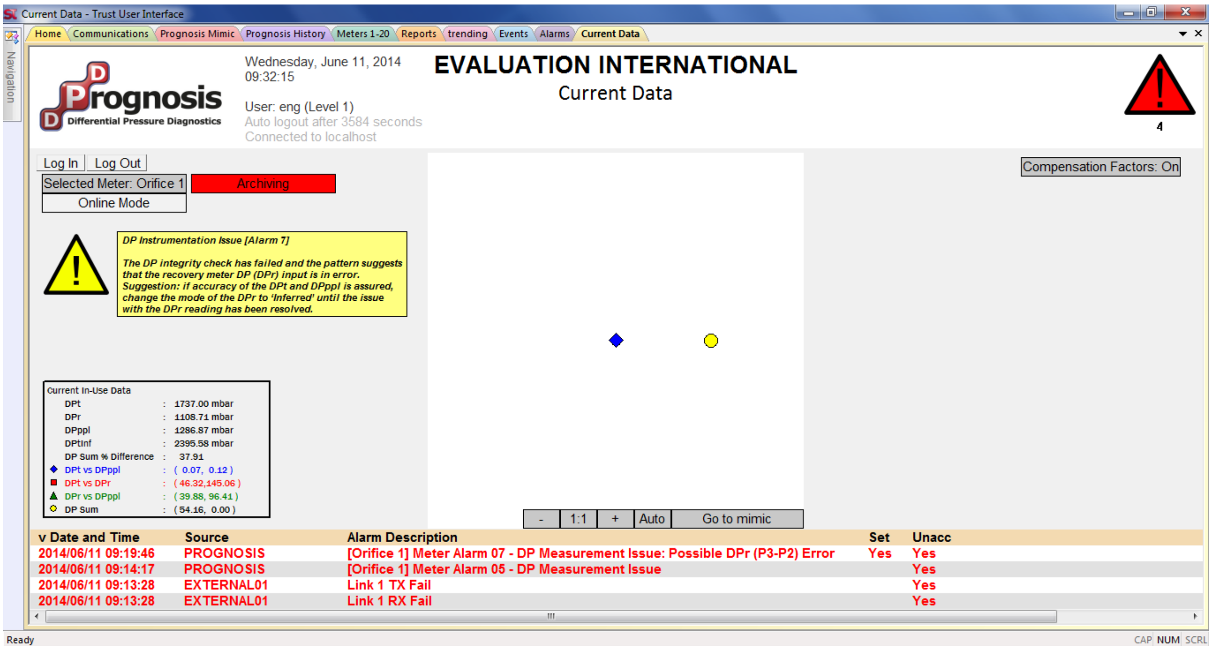


Figure 79 – Snapshot of the test with the (simulated) incorrectly entered DP-transmitter range (DPr)

PROGNOSIS raises an alarm which clearly indicates an integrity issue with the DPr measurement. Using this example and assuming that the DPt and the DPppl measurements are accurate, the actual DPr is approximately 450.13 mbar (i.e., DPt – DPppl). Therefore the reported DPr of 1108.71 mbar is in error by approximately +59.4 %. This gross error sees the ‘DPt vs DPr’ and the ‘DPr vs DPppl’ points outside of the visible plot.

b) DPppl incorrectly ranged - causing DPppl to read approximately 5500 mbar (21.6 mA)

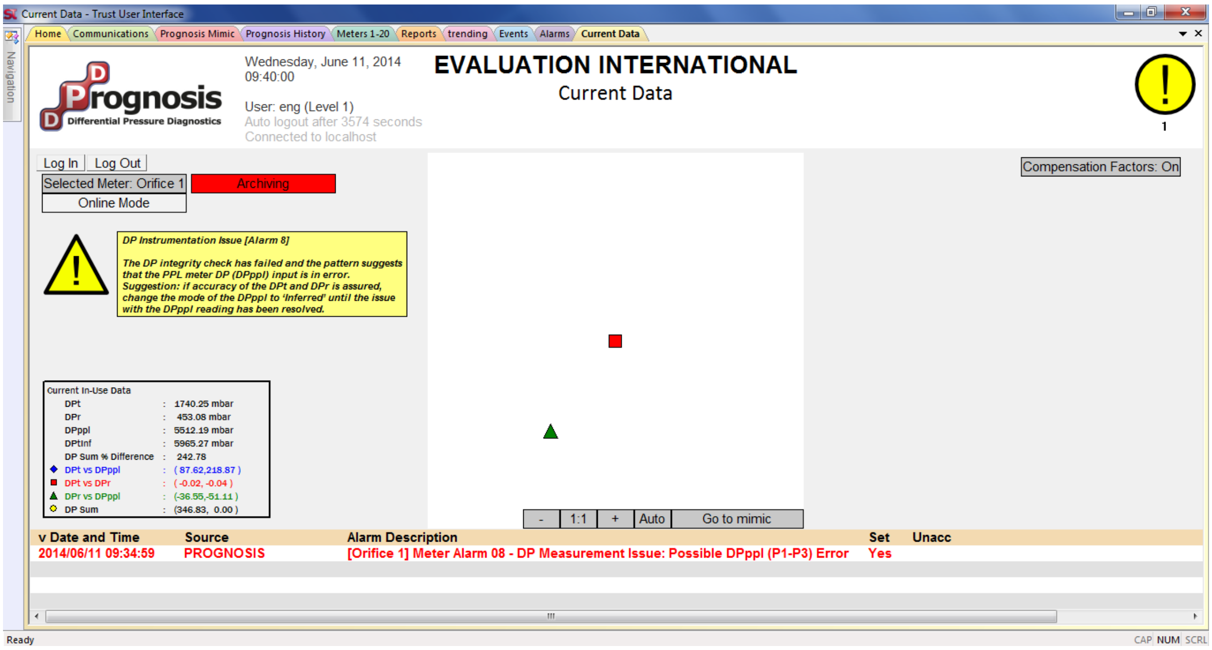


Figure 80 – Snapshot of the test with the (simulated) incorrectly entered DP-transmitter range (DPppl)

PROGNOSIS raises an alarm which clearly indicates an integrity issue with the DPppl measurement. Using this example and assuming that the DPt and the DPr measurements are accurate, the actual DPppl is approximately 1287.17 mbar (i.e., DPt – DPr). Therefore the reported DPppl of 5512.19 mbar is in error by approximately +328 %. This gross error sees the 'DP Sum' and the 'DPt vs DPppl' points outside of the visible plot.

c) DPt incorrectly ranged - causing DPt to read approximately 5500 mbar (21.6 mA)

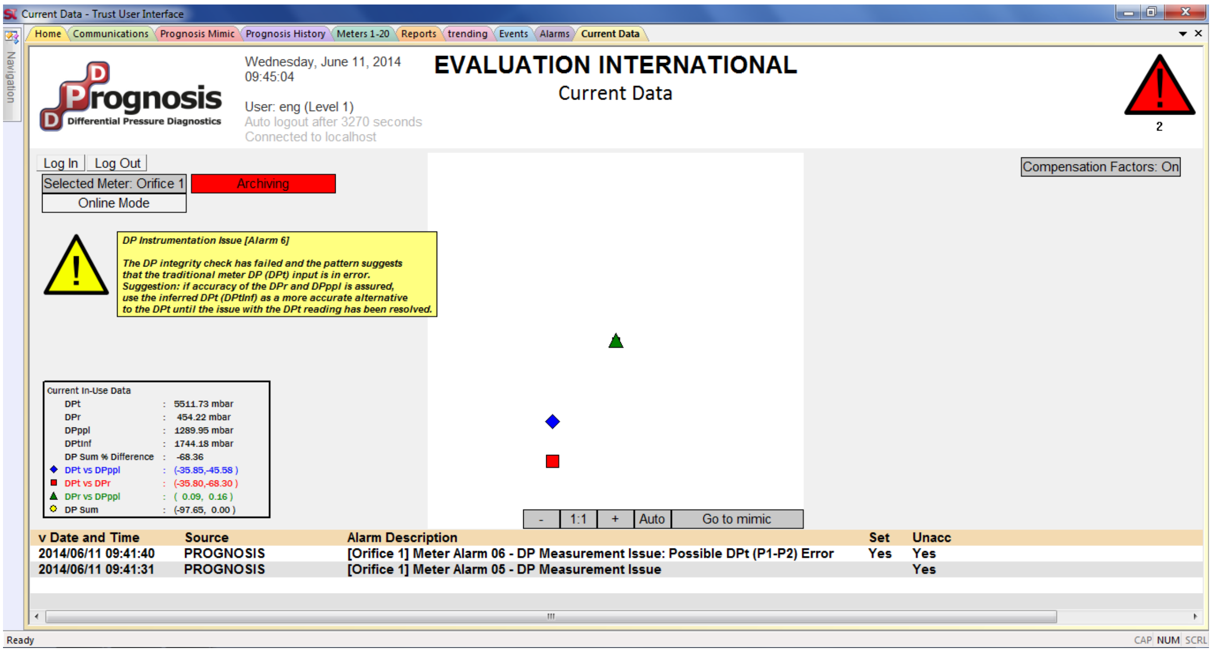


Figure 81 – Snapshot of the test with the (simulated) incorrectly entered DP-transmitter range (DPt)

PROGNOSIS clearly raises an alarm indicating an error in reported DPt (and hence in the reported flow rate prediction). Using this example and assuming that the DPr and DPppl measurements are accurate, the actual DPt is 1744.18 mbar. There reported DPt is 5511.73 mbar which is in error by approximately +216 %; the resulting flow rate prediction has a bias of approximately +77.6 %. This gross error sees the 'DP Sum' point outside of the visible plot.

<u>Result:</u> In each test case PROGNOSIS indicated a 'DP instrumentation issue' since the DP integrity check has failed for the (right) DP-transmitter where the measurement range was incorrectly set.

4.11. Test 11 – Influence of the medium temperature

Objective – determine whether the DUT is adversely affected by a change in medium temperature
Criteria – DUT should react in accordance with the manufacturers' specifications.

a) *Calibration measurements at 30 ˚C (Re numbers 250 000 and 300 000)*
b) *Calibration measurements at 40 ˚C (Re numbers 250 000 and 300 000)*
c) *Calibration measurements at 50 ˚C (Re numbers 250 000 and 300 000)*
d) *Calibration measurements at 60 ˚C (Re numbers 250 000 and 300 000)*
e) *Calibration measurements at 70 ˚C (Re numbers 250 000 and 300 000)*

(Note: The temperature sensor T_{VM4} in the following figures is installed in a pipeline which was not used for the evaluation tests.)

$I_{min=}$	4.00 mA	4.00 mA
$I_{max=}$	20.00 mA	20.00 mA
$q_{min=}$	0.00 kPa	0.00 kg/min
$q_{max=}$	500.00 kPa	3000.00 kg/min

p/l= **57.62** p/kg= **100.00**

			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	q_{vner}	$q_{m T,p sl in}$	p_U	$p_{slinga in}$	$p_{slingan ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1 brutto}$	$\delta p_{1 brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan in}$	$\rho(T_{sl in},p_{sl in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master 1}$	$T_{slinga ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm³**	**kg/m³**	**kg/m³**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	973.97	969.18	267.8	271.0	251.4	57.4358	-0.320	99.9343	-0.066	6.5235	78.8587	9.1687	0.007	0.994955	995.0848	995.0834	0.000756	24.79	32.52	32.57	216.112
2	974.09	969.33	267.8	270.6	251.6	57.4699	-0.260	99.9445	-0.055	6.5258	78.9324	9.1704	0.025	0.994987	995.1164	995.1151	0.000758	24.82	32.35	32.51	216.049
3	973.78	969.12	267.8	270.7	251.3	57.4533	-0.289	99.9321	-0.068	6.5227	78.8348	9.1682	0.004	0.995080	995.2093	995.2080	0.000763	24.84	32.05	32.37	216.149
4	973.15	968.58	267.8	270.3	251.1	57.4594	-0.279	99.9434	-0.057	6.5201	78.7547	9.1661	0.020	0.995173	995.3019	995.3008	0.000767	24.86	31.77	32.12	216.253
5	973.03	968.54	267.8	270.8	251.1	57.4445	-0.304	99.9323	-0.068	6.5190	78.7187	9.1651	0.003	0.995259	995.3884	995.3870	0.000771	24.88	31.49	31.82	216.313
mv=	**973.60**	**968.95**	**267.8**	**270.7**	**251.3**	**57.4526**	**-0.291**	**99.937**	**-0.063**	**6.5222**	**78.820**	**9.1677**	**0.012**	**0.994955**	**995.220**	**995.219**	**0.000763**	**20.00**	**32.04**	**32.28**	**216.175**
w=	1.05	0.78	0.0	0.7	0.5	0.0342	0.059	0.012	0.012	0.0068	0.214	0.0053	0.022	0.000000	0.304	0.304	0.000015	0.09	1.03	0.74	0.264
s=	0.48	0.36	0.0	0.3	0.2	0.0132	0.023	0.006	0.006	0.0027	0.085	0.0021	0.010	0.000127	0.127	0.127	0.000006	0.04	0.42	0.31	0.107

	[m]		β:	0.5
	D_p (20°C):	D_p (T):	d_O (m):	
$\delta p_{1 noll}$ (kPa)	0.10226	0.102281	0.051141	
0.0197				

$\delta p_{1 korr}$	q_v	v_D	$T_{slinga in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
78.8390	16.23	1.98	32.52	265825	531650	0.60786	0.60512	0.452
78.9127	16.23	1.98	32.42	265329	530658	0.60766	0.60512	0.419
78.8151	16.23	1.98	32.13	263694	527388	0.60788	0.60513	0.453
78.7350	16.22	1.97	31.84	261961	523922	0.60782	0.60514	0.442
78.6990	16.22	1.97	31.57	260471	520943	0.60791	0.60515	0.456
78.8002	**16.23**	**1.97**	**32.09**	**263456**	**526912**	**0.60782**	**0.60513**	**0.444**
0.2137	0.02	0.00	0.95	5354	10707	0.00025	0.00003	0.037
0.0850	0.01	0.00	0.40	2254	4508	0.00010	0.00001	0.015

Figure 82 – Calibration measurement at Re = 250 000 (30 ˚C)

$I_{min=}$	4.00 mA	4.00 mA
$I_{max=}$	20.00 mA	20.00 mA
$q_{min=}$	0.00 kPa	0.00 kg/min
$q_{max=}$	500.00 kPa	3000.00 kg/min

p/l= **57.62** p/kg= **100.00**

			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	q_{vner}	$q_{m T,p sl in}$	p_U	$p_{slinga in}$	$p_{slingan ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1 brutto}$	$\delta p_{1 brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan in}$	$\rho(T_{sl in},p_{sl in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master 1}$	$T_{slinga ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm³**	**kg/m³**	**kg/m³**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	1536.93	1530.79	267.8	197.3	161.6	57.4246	-0.339	99.9620	-0.038	10.3037	196.9914	12.1605	-0.035	0.995909	996.0044	996.0358	0.000807	25.10	29.39	29.60	136.914
2	1539.20	1533.11	267.8	196.6	159.6	57.4133	-0.359	99.9539	-0.046	10.3236	197.6131	12.1725	-0.040	0.995952	996.0470	996.0787	0.000809	25.12	29.25	29.43	136.734
3	1537.26	1531.24	267.8	196.6	161.7	57.4070	-0.370	99.9730	-0.027	10.3070	197.0936	12.1636	-0.027	0.995992	996.0876	996.1193	0.000812	25.13	29.11	29.30	136.884
4	1538.33	1532.37	267.8	196.3	159.7	57.4051	-0.373	99.9530	-0.047	10.3156	197.3631	12.1684	-0.043	0.996033	996.1284	996.1603	0.000814	25.15	28.98	29.15	136.811
5	1538.00	1532.11	267.8	196.6	161.6	57.4046	-0.374	99.9677	-0.032	10.3150	197.3432	12.1683	-0.027	0.996073	996.1684	996.2002	0.000817	25.16	28.84	29.02	136.816
mv=	**1537.94**	**1531.92**	**267.8**	**196.7**	**160.8**	**57.4109**	**-0.363**	**99.962**	**-0.038**	**10.3130**	**197.281**	**12.1667**	**-0.034**	**0.995909**	**996.087**	**996.119**	**0.000812**	**20.00**	**29.12**	**29.30**	**136.832**
w=	2.27	2.33	0.0	1.0	2.0	0.0200	0.035	0.020	0.020	0.0199	0.622	0.0120	0.016	0.000000	0.164	0.164	0.000010	0.06	0.55	0.57	0.180
s=	0.90	0.92	0.0	0.4	1.1	0.0084	0.015	0.009	0.009	0.0078	0.245	0.0047	0.007	0.000065	0.065	0.065	0.000004	0.03	0.22	0.23	0.070

	[m]		β:	0.5
	D_p (20°C):	D_p (T):	d_O (m):	
$\delta p_{1 noll}$ (kPa)	0.10226	0.102276	0.051138	
-0.0119				

$\delta p_{1 korr}$	q_v	v_D	$T_{slinga in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
197.0033	25.62	3.12	29.45	393675	787350	0.60713	0.60463	0.413
197.6250	25.65	3.12	29.30	393051	786102	0.60708	0.60463	0.405
197.1055	25.62	3.12	29.16	391415	782830	0.60713	0.60464	0.412
197.3750	25.64	3.12	29.02	390529	781058	0.60715	0.60464	0.415
197.3551	25.63	3.12	28.89	389317	778634	0.60706	0.60465	0.400
197.2928	**25.63**	**3.12**	**29.17**	**391597**	**783195**	**0.60711**	**0.60464**	**0.409**
0.6217	0.04	0.00	0.56	4358	8715	0.00008	0.00001	0.015
0.2449	0.01	0.00	0.22	1789	3578	0.00004	0.00001	0.006

Figure 83 – Calibration measurement at Re = 400 000 (30 ˚C)

								$I_{min=}$	4.00 mA	4.00 mA											
								$I_{max=}$	20.00 mA	20.00 mA											
								$q_{min=}$	0.00 kPa	0.00 kg/min											
				p/l= **57.62**		p/kg= **100.00**		$q_{max=}$	500.00 kPa	3000.00 kg/min											
			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	$q_{v\,ner}$	$q_{m\,T,p\,sl\,in}$	p_U	$p_{slinga\,in}$	$p_{slingan\,ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1\,brutto}$	$\delta p_{1\,brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan\,in}$	$\rho(T_{sl\,in},p_{sl\,in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master\,1}$	$T_{slinga\,ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm³**	**kg/m³**	**kg/m³**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	790.38	784.50	298.4	161.2	148.4	57.4619	-0.274	99.9615	-0.039	5.6588	51.8364	8.1869	0.077	0.992479	992.5634	992.6234	0.000659	30.51	39.53	39.58	75.557
2	790.15	784.29	298.4	161.6	148.3	57.4759	-0.250	99.9664	-0.034	5.6570	51.7797	8.1853	0.066	0.992492	992.5767	992.6366	0.000659	30.51	39.48	39.62	76.324
3	790.62	784.76	298.4	161.4	148.6	57.4603	-0.277	99.9486	-0.051	5.6591	51.8455	8.1881	0.074	0.992512	992.5967	992.6567	0.000660	30.50	39.43	39.64	76.118
4	792.96	787.12	298.4	151.4	143.8	57.4499	-0.295	99.9523	-0.048	5.6686	52.1423	8.2001	0.059	0.992558	992.6385	992.7028	0.000661	30.48	39.31	39.45	75.897
5	792.07	786.27	298.4	161.7	149.3	57.4561	-0.284	99.9571	-0.043	5.6646	52.0194	8.1968	0.089	0.992588	992.6726	992.7325	0.000662	30.47	39.24	39.49	76.111
6	794.39	788.58	298.4	162.6	150.3	57.4444	-0.305	99.9674	-0.033	5.6749	52.3412	8.2080	0.061	0.992603	992.6878	992.7473	0.000663	30.47	39.19	39.43	75.168
mv=	**791.76**	**785.92**	**298.4**	**160.0**	**148.1**	**57.4581**	**-0.281**	**99.959**	**-0.041**	**5.6638**	**51.994**	**8.1942**	**0.071**	**0.992479**	**992.623**	**992.683**	**0.000660**	**20.00**	**39.36**	**39.54**	**75.862**
w=	4.24	4.29	0.0	11.2	6.5	0.0315	0.055	0.019	0.019	0.0180	0.562	0.0227	0.030	0.000000	0.124	0.124	0.000004	0.05	0.34	0.21	1.156
s=	1.69	1.71	0.0	4.2	2.3	0.0109	0.019	0.008	0.008	0.0070	0.217	0.0090	0.011	0.000052	0.052	0.052	0.000002	0.02	0.14	0.09	0.428

	[m]	β:	0.5
	D_p (20°C):	D_p (T):	d_O (m):
$\delta p_{1\,noll}$ (kPa)	0.10226	0.102294	0.051147
0.0545			

$\delta p_{1\,korr}$	q_v	v_D	$T_{slinga\,in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
51.7818	13.17	1.60	39.55	247137	494273	0.60772	0.60522	0.412
51.7252	13.17	1.60	39.52	246907	493815	0.60788	0.60523	0.439
51.7909	13.18	1.60	39.47	246810	493620	0.60786	0.60523	0.435
52.0878	13.22	1.61	39.34	246981	493962	0.60794	0.60523	0.448
51.9649	13.20	1.61	39.26	246346	492691	0.60798	0.60523	0.455
52.2867	13.24	1.61	39.23	246887	493774	0.60789	0.60523	0.440
51.9395	**13.20**	**1.61**	**39.39**	**246845**	**493689**	**0.60788**	**0.60523**	**0.438**
0.5615	0.07	0.01	0.33	791	1582	0.00026	0.00000	0.043
0.2173	0.03	0.00	0.14	268	537	0.00009	0.00000	0.015

Figure 84 – Calibration measurement at Re = 250 000 (40 °C)

								$I_{min=}$	4.00 mA	4.00 mA											
								$I_{max=}$	20.00 mA	20.00 mA											
								$q_{min=}$	0.00 kPa	0.00 kg/min											
				p/l= **57.62**		p/kg= **100.00**		$q_{max=}$	500.00 kPa	3000.00 kg/min											
			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	$q_{v\,ner}$	$q_{m\,T,p\,sl\,in}$	p_U	$p_{slinga\,in}$	$p_{slingan\,ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1\,brutto}$	$\delta p_{1\,brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan\,in}$	$\rho(T_{sl\,in},p_{sl\,in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master\,1}$	$T_{slinga\,ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm³**	**kg/m³**	**kg/m³**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	1263.50	1254.42	298.4	243.4	219.9	57.4228	-0.342	99.9736	-0.026	8.2451	132.6594	10.6861	-0.050	0.992694	992.8143	992.8383	0.000666	30.43	38.96	39.07	166.624
2	1264.23	1255.19	298.4	242.9	220.3	57.4224	-0.343	99.9823	-0.018	8.2517	132.8663	10.6909	-0.040	0.992734	992.8541	992.8784	0.000667	30.41	38.86	38.96	166.500
3	1264.11	1255.12	298.4	243.4	220.2	57.4240	-0.340	99.9736	-0.026	8.2509	132.8415	10.6899	-0.049	0.992775	992.8950	992.9191	0.000668	30.40	38.75	38.84	166.543
4	1264.09	1255.15	298.4	242.8	220.5	57.4205	-0.346	99.9836	-0.016	8.2499	132.8098	10.6909	-0.036	0.992810	992.9296	992.9540	0.000670	30.38	38.66	38.75	166.517
5	1264.35	1255.45	298.4	243.1	220.4	57.4049	-0.373	99.9713	-0.029	8.2513	132.8540	10.6917	-0.048	0.992841	992.9613	992.9856	0.000671	30.36	38.58	38.65	166.510
6	1263.37	1254.50	298.4	242.2	220.3	57.4286	-0.332	99.9827	-0.017	8.2473	132.7276	10.6874	-0.037	0.992858	992.9778	993.0024	0.000671	30.33	38.55	38.57	166.611
mv=	**1263.94**	**1254.97**	**298.4**	**243.0**	**220.3**	**57.4205**	**-0.346**	**99.978**	**-0.022**	**8.2494**	**132.793**	**10.6895**	**-0.043**	**0.992694**	**992.905**	**992.930**	**0.000669**	**20.00**	**38.73**	**38.81**	**166.551**
w=	0.98	1.03	0.0	1.2	0.6	0.0237	0.041	0.012	0.012	0.0066	0.207	0.0056	0.014	0.000000	0.164	0.164	0.000006	0.10	0.41	0.50	0.124
s=	0.40	0.41	0.0	0.4	0.2	0.0081	0.014	0.006	0.006	0.0026	0.082	0.0022	0.007	0.000063	0.063	0.063	0.000002	0.04	0.16	0.19	0.054

	[m]	β:	0.5
	D_p (20°C):	D_p (T):	d_O (m):
$\delta p_{1\,noll}$ (kPa)	0.10226	0.102293	0.051146
0.0281			

$\delta p_{1\,korr}$	q_v	v_D	$T_{slinga\,in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
132.6313	21.06	2.56	38.98	390932	781864	0.60713	0.60464	0.412
132.8382	21.07	2.56	38.88	390376	780752	0.60702	0.60464	0.393
132.8134	21.07	2.56	38.77	389546	779091	0.60703	0.60464	0.395
132.7817	21.07	2.56	38.67	388861	777722	0.60711	0.60465	0.407
132.8260	21.07	2.56	38.59	388323	776645	0.60714	0.60465	0.412
132.6996	21.06	2.56	38.54	387693	775386	0.60696	0.60465	0.383
132.7650	**21.07**	**2.56**	**38.74**	**389288**	**778577**	**0.60706**	**0.60465**	**0.400**
0.2069	0.02	0.00	0.44	3239	6478	0.00017	0.00001	0.029
0.0823	0.01	0.00	0.17	1234	2468	0.00007	0.00000	0.012

Figure 85 – Calibration measurement at Re = 400 000 (40 °C)

$I_{min=}$	4.00 mA	4.00 mA
$I_{max=}$	20.00 mA	20.00 mA
$q_{min=}$	0.00 kPa	0.00 kg/min
$q_{max=}$	500.00 kPa	3000.00 kg/min

p/l= **57.62** p/kg= **100.00**

			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	q_{vner}	$q_{m\,T,p\,sl\,in}$	p_U	$p_{slinga\,in}$	$p_{slingan\,ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1\,brutto}$	$\delta p_{1\,brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan\,in}$	$\rho(T_{sl\,in},p_{sl\,in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master\,1}$	$T_{slinga\,ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm³**	**kg/m³**	**kg/m³**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	668.64	660.98	298.4	229.0	222.3	57.4639	-0.271	99.9591	-0.041	5.1808	36.8985	7.5267	0.052	0.988428	988.5441	988.5743	0.000553	32.59	49.31	49.41	89.343
2	668.05	660.41	298.4	228.7	221.9	57.4574	-0.282	99.9547	-0.045	5.1781	36.8162	7.5229	0.032	0.988455	988.5703	988.6007	0.000554	32.60	49.26	49.42	90.305
3	668.47	660.84	298.4	228.5	222.2	57.4299	-0.330	99.9461	-0.054	5.1801	36.8779	7.5252	0.033	0.988479	988.5948	988.6252	0.000554	32.60	49.20	49.44	90.057
4	672.86	665.23	298.4	217.7	213.8	57.4192	-0.349	99.9456	-0.054	5.1957	37.3653	7.5492	0.049	0.988556	988.6668	988.7019	0.000556	32.63	49.04	49.18	89.474
5	670.49	662.93	298.4	230.8	223.9	57.4240	-0.340	99.9500	-0.050	5.1881	37.1281	7.5369	0.048	0.988596	988.7129	988.7423	0.000557	32.65	48.94	49.22	89.942
6	670.51	662.96	298.4	230.6	224.0	57.4528	-0.290	99.9598	-0.040	5.1879	37.1234	7.5374	0.056	0.988622	988.7379	988.7673	0.000557	32.65	48.88	49.15	89.085
mv=	**669.84**	**662.23**	**298.4**	**227.5**	**221.4**	**57.4412**	**-0.310**	**99.953**	**-0.047**	**5.1851**	**37.035**	**7.5330**	**0.045**	**0.988428**	**988.638**	**988.669**	**0.000555**	**20.00**	**49.11**	**49.30**	**89.701**
w=	4.81	4.82	0.0	13.1	10.1	0.0448	0.078	0.014	0.014	0.0176	0.549	0.0263	0.024	0.000000	0.194	0.193	0.000004	0.06	0.43	0.30	1.220
s=	1.82	1.83	0.0	4.9	3.8	0.0191	0.033	0.006	0.006	0.0067	0.208	0.0100	0.010	0.000080	0.080	0.080	0.000002	0.03	0.18	0.13	0.471

	[m]		β:	0.5
	D_p (20°C):	D_p (T):	d_O (m):	
$\delta p_{1\,noll}$ (kPa)	0.10226	0.102311	0.051155	
0.0251				

$\delta p_{1\,korr}$	q_v	v_D	$T_{slinga\,in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
36.8735	11.14	1.36	49.34	247893	495786	0.60782	0.60522	0.430
36.7911	11.13	1.35	49.28	247432	494864	0.60797	0.60522	0.454
36.8529	11.14	1.36	49.22	247364	494728	0.60785	0.60522	0.434
37.3402	11.21	1.36	49.05	248284	496567	0.60785	0.60522	0.435
37.1031	11.17	1.36	48.96	247043	494086	0.60767	0.60522	0.404
37.0983	11.18	1.36	48.90	246821	493641	0.60773	0.60523	0.414
37.0098	**11.16**	**1.36**	**49.12**	**247473**	**494945**	**0.60782**	**0.60522**	**0.428**
0.5491	0.08	0.01	0.43	1463	2926	0.00030	0.00001	0.050
0.2082	0.03	0.00	0.18	540	1080	0.00010	0.00000	0.018

Figure 86 – Calibration measurement at Re = 250 000 (50 ˚C)

$I_{min=}$	4.00 mA	4.00 mA
$I_{max=}$	20.00 mA	20.00 mA
$q_{min=}$	0.00 kPa	0.00 kg/min
$q_{max=}$	500.00 kPa	3000.00 kg/min

p/l= **57.62** p/kg= **100.00**

			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	q_{vner}	$q_{m\,T,p\,sl\,in}$	p_U	$p_{slinga\,in}$	$p_{slingan\,ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1\,brutto}$	$\delta p_{1\,brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan\,in}$	$\rho(T_{sl\,in},p_{sl\,in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master\,1}$	$T_{slinga\,ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm³**	**kg/m³**	**kg/m³**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	1065.27	1052.29	298.4	162.5	148.6	57.4096	-0.365	99.9773	-0.023	7.0024	93.8235	9.6115	-0.004	0.987733	987.8201	987.8792	0.000539	32.31	50.86	50.92	197.706
2	1065.90	1053.01	298.4	162.3	149.0	57.4187	-0.349	99.9878	-0.012	7.0060	93.9374	9.6161	0.009	0.987825	987.9123	987.9714	0.000541	32.35	50.66	50.81	197.555
3	1066.50	1053.70	298.4	162.8	149.1	57.4083	-0.367	99.9750	-0.025	7.0106	94.0819	9.6189	-0.005	0.987910	987.9974	988.0564	0.000543	32.38	50.48	50.60	197.475
4	1068.41	1055.67	298.4	163.2	149.9	57.4132	-0.359	99.9856	-0.014	7.0204	94.3885	9.6303	0.009	0.987986	988.0732	988.1320	0.000544	32.42	50.31	50.43	197.087
5	1068.73	1056.07	298.4	163.6	149.8	57.4079	-0.368	99.9746	-0.025	7.0217	94.4278	9.6316	-0.004	0.988068	988.1552	988.2138	0.000546	32.45	50.13	50.25	197.060
6	1068.62	1056.05	298.4	163.1	149.8	57.4015	-0.379	99.9816	-0.018	7.0237	94.4905	9.6321	0.007	0.988147	988.2340	988.2929	0.000547	32.48	49.95	50.08	197.047
mv=	**1067.24**	**1054.47**	**298.4**	**162.9**	**149.4**	**57.4099**	**-0.365**	**99.980**	**-0.020**	**7.0141**	**94.192**	**9.6234**	**0.002**	**0.987733**	**988.032**	**988.091**	**0.000543**	**20.00**	**50.40**	**50.52**	**197.322**
w=	3.46	3.78	0.0	1.2	1.3	0.0172	0.030	0.013	0.013	0.0213	0.667	0.0206	0.015	0.000000	0.414	0.414	0.000008	0.17	0.91	0.84	0.660
s=	1.53	1.67	0.0	0.5	0.6	0.0058	0.010	0.006	0.006	0.0090	0.281	0.0090	0.007	0.000154	0.154	0.154	0.000003	0.06	0.34	0.32	0.291

	[m]		β:	0.5
	D_p (20°C):	D_p (T):	d_O (m):	
$\delta p_{1\,noll}$ (kPa)	0.10226	0.102313	0.051156	
0.0292				

$\delta p_{1\,korr}$	q_v	v_D	$T_{slinga\,in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
93.7943	17.75	2.16	50.87	404917	809834	0.60691	0.60460	0.382
93.9082	17.76	2.16	50.67	403838	807677	0.60693	0.60460	0.385
94.0527	17.77	2.16	50.48	402848	805696	0.60683	0.60461	0.368
94.3593	17.81	2.17	50.32	402483	804965	0.60696	0.60461	0.389
94.3986	17.81	2.17	50.14	401423	802846	0.60704	0.60461	0.401
94.4612	17.81	2.17	49.96	400241	800482	0.60680	0.60461	0.361
94.1624	**17.79**	**2.16**	**50.41**	**402625**	**805250**	**0.60691**	**0.60461**	**0.381**
0.6670	0.06	0.01	0.91	4676	9352	0.00024	0.00001	0.040
0.2814	0.03	0.00	0.34	1669	3337	0.00009	0.00000	0.014

Figure 87 – Calibration measurement at Re = 400 000 (50 ˚C)

$I_{min=}$	4.00 mA		4.00 mA
$I_{max=}$	20.00 mA		20.00 mA
$q_{min=}$	0.00 kPa		0.00 kg/min
$q_{max=}$	500.00 kPa		3000.00 kg/min

p/l= **57.62** p/kg= **100.00**

			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	q_{vner}	$q_{m\,T,p\,sl\,in}$	p_U	$p_{slinga\,in}$	$p_{slingan\,ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1\ brutto}$	$\delta p_{1\ brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan\,in}$	$\rho(T_{sl\,in},p_{sl\,in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master\,1}$	$T_{slinga\,ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm³**	**kg/m³**	**kg/m³**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	573.79	564.55	298.4	227.4	221.1	57.4199	-0.347	99.9655	-0.035	4.8646	27.0192	7.0168	0.206	0.983773	983.8915	983.9225	0.000473	38.11	59.07	59.03	104.145
2	573.30	564.08	298.4	227.2	220.8	57.4388	-0.314	99.9697	-0.030	4.8635	26.9855	7.0138	0.189	0.983808	983.9261	983.9571	0.000474	38.09	59.00	59.11	105.263
3	574.01	564.80	298.4	227.3	221.4	57.4021	-0.378	99.9623	-0.038	4.8651	27.0332	7.0182	0.209	0.983843	983.9614	983.9924	0.000474	38.08	58.93	59.12	104.911
4	574.43	565.26	298.4	211.1	206.2	57.4345	-0.322	99.9628	-0.037	4.8664	27.0751	7.0187	0.143	0.983924	984.0350	984.0730	0.000475	38.04	58.78	58.83	104.837
5	574.04	564.90	298.4	227.5	221.5	57.4250	-0.338	99.9659	-0.034	4.8660	27.0635	7.0174	0.162	0.983963	984.0812	984.1121	0.000476	38.01	58.69	58.83	105.087
6	574.35	565.23	298.4	227.5	221.7	57.4310	-0.328	99.9742	-0.026	4.8673	27.1023	7.0189	0.157	0.984000	984.1185	984.1494	0.000476	38.00	58.61	58.83	104.034
mv=	**573.99**	**564.80**	**298.4**	**224.7**	**218.8**	**57.4252**	**-0.338**	**99.967**	**-0.033**	**4.8655**	**27.046**	**7.0173**	**0.178**	**0.983773**	**984.002**	**984.034**	**0.000475**	**20.00**	**58.85**	**58.96**	**104.713**
w=	1.14	1.18	0.0	16.4	15.5	0.0367	0.064	0.012	0.012	0.0037	0.117	0.0052	0.066	0.000000	0.227	0.227	0.000003	0.11	0.45	0.29	1.230
s=	0.41	0.44	0.0	6.6	6.2	0.0132	0.023	0.005	0.005	0.0013	0.042	0.0019	0.027	0.000091	0.090	0.091	0.000001	0.04	0.18	0.14	0.506

	[m]		β:	0.5
	D_p (20°C):	D_p (T):	d_O (m):	
$\delta p_{1\ noll}$ (kPa)	0.10226	0.102328	0.051164	
0.0251				

$\delta p_{1\ korr}$	q_v	v_D	$T_{slinga\,in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
26.9941	9.56	1.16	59.05	247405	494811	0.60798	0.60522	0.456
26.9604	9.55	1.16	58.99	246943	493887	0.60785	0.60523	0.433
27.0081	9.57	1.16	58.92	246996	493992	0.60807	0.60523	0.471
27.0500	9.57	1.16	58.76	246599	493198	0.60808	0.60523	0.471
27.0384	9.57	1.16	58.68	246152	492304	0.60781	0.60523	0.426
27.0772	9.57	1.16	58.61	246015	492030	0.60771	0.60523	0.409
27.0214	**9.57**	**1.16**	**58.83**	**246685**	**493370**	**0.60792**	**0.60523**	**0.444**
0.1168	0.02	0.00	0.45	1391	2781	0.00037	0.00001	0.061
0.0421	0.01	0.00	0.18	534	1067	0.00015	0.00000	0.025

Figure 88 – Calibration measurement at Re = 250 000 (60 °C)

$I_{min=}$	4.00 mA		4.00 mA
$I_{max=}$	20.00 mA		20.00 mA
$q_{min=}$	0.00 kPa		0.00 kg/min
$q_{max=}$	500.00 kPa		3000.00 kg/min

p/l= **57.62** p/kg= **100.00**

			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	q_{vner}	$q_{m\,T,p\,sl\,in}$	p_U	$p_{slinga\,in}$	$p_{slingan\,ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1\ brutto}$	$\delta p_{1\ brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan\,in}$	$\rho(T_{sl\,in},p_{sl\,in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master\,1}$	$T_{slinga\,ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm³**	**kg/m³**	**kg/m³**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	924.74	910.20	298.4	220.5	209.1	57.4147	-0.356	99.9812	-0.019	6.2524	70.3871	8.8539	0.001	0.984156	984.2708	984.3048	0.000479	37.90	58.33	58.32	227.808
2	924.88	910.36	298.4	220.1	209.1	57.4085	-0.367	99.9947	-0.005	6.2546	70.4558	8.8557	0.021	0.984187	984.3014	984.3355	0.000479	37.86	58.28	58.21	227.735
3	924.94	910.39	298.4	219.9	209.0	57.3887	-0.401	99.9777	-0.022	6.2542	70.4443	8.8548	-0.002	0.984156	984.2707	984.3049	0.000479	37.81	58.40	58.15	227.758
4	925.93	911.30	298.4	219.9	209.3	57.4092	-0.366	99.9885	-0.011	6.2595	70.6090	8.8604	0.016	0.984083	984.1981	984.2323	0.000478	37.78	58.54	58.22	227.479
5	924.95	909.82	298.4	219.3	208.7	57.4204	-0.346	99.9776	-0.022	6.2531	70.4091	8.8515	-0.005	0.983526	983.6408	983.6752	0.000470	37.64	59.71	59.08	227.765
6	925.57	910.21	298.4	219.1	208.9	57.4077	-0.368	99.9907	-0.009	6.2553	70.4777	8.8547	0.016	0.983297	983.4120	983.4466	0.000467	37.60	60.14	59.42	227.579
mv=	**925.17**	**910.38**	**298.4**	**219.8**	**209.0**	**57.4082**	**-0.368**	**99.985**	**-0.015**	**6.2548**	**70.464**	**8.8552**	**0.008**	**0.984156**	**984.016**	**984.050**	**0.000475**	**20.00**	**58.90**	**58.57**	**227.687**
w=	1.19	1.48	0.0	1.3	0.6	0.0316	0.055	0.017	0.017	0.0071	0.222	0.0089	0.026	0.000000	0.889	0.889	0.000013	0.29	1.86	1.27	0.329
s=	0.47	0.49	0.0	0.5	0.2	0.0107	0.019	0.007	0.007	0.0025	0.078	0.0029	0.011	0.000387	0.387	0.387	0.000005	0.12	0.81	0.54	0.129

	[m]		β:	0.5
	D_p (20°C):	D_p (T):	d_O (m):	
$\delta p_{1\ noll}$ (kPa)	0.10226	0.102327	0.051163	
0.0258				

$\delta p_{1\ korr}$	q_v	v_D	$T_{slinga\,in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
70.3613	15.41	1.87	58.30	394297	788594	0.60703	0.60463	0.396
70.4300	15.41	1.87	58.24	393998	787996	0.60683	0.60463	0.364
70.4185	15.42	1.87	58.30	394381	788763	0.60691	0.60463	0.377
70.5832	15.43	1.88	58.44	395646	791291	0.60683	0.60463	0.364
70.3833	15.42	1.87	59.54	401658	803316	0.60686	0.60461	0.371
70.4519	15.43	1.88	59.98	404554	809107	0.60689	0.60460	0.379
70.4381	**15.42**	**1.87**	**58.80**	**397422**	**794845**	**0.60689**	**0.60462**	**0.375**
0.2219	0.02	0.00	1.75	10556	21111	0.00020	0.00003	0.033
0.0782	0.01	0.00	0.76	4532	9064	0.00007	0.00001	0.012

Figure 89 – Calibration measurement at Re = 400 000 (60 °C)

$I_{min=}$	4.00 mA	4.00 mA
$I_{max=}$	20.00 mA	20.00 mA
$q_{min=}$	0.00 kPa	0.00 kg/min
$q_{max=}$	500.00 kPa	3000.00 kg/min

p/l= **57.62** p/kg= **100.00**

			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	q_{vner}	$q_{m\,T,p\,sl\,in}$	p_U	$p_{slinga\,in}$	$p_{slingan\,ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1\,brutto}$	$\delta p_{1\,brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan\,in}$	$\rho(T_{sl\,in},p_{sl\,in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master\,1}$	$T_{slinga\,ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm³**	**kg/m³**	**kg/m³**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	503.56	491.96	298.4	224.7	219.3	57.4143	-0.357	99.9208	-0.079	4.6625	20.7024	6.6262	0.104	0.976832	976.9507	976.9832	0.000394	39.73	71.83	71.72	118.719
2	502.65	491.10	298.4	224.1	218.4	57.4236	-0.341	99.9295	-0.071	4.6597	20.6153	6.6210	0.080	0.976900	977.0187	977.0515	0.000395	39.74	71.71	71.74	120.108
3	503.61	492.07	298.4	224.4	219.3	57.4439	-0.306	99.9198	-0.080	4.6626	20.7072	6.6268	0.104	0.976972	977.0903	977.1230	0.000396	39.74	71.59	71.66	119.625
4	504.28	492.79	298.4	211.7	208.2	57.4438	-0.306	99.9163	-0.084	4.6643	20.7597	6.6306	0.102	0.977108	977.2207	977.2589	0.000397	39.74	71.45	71.36	119.472
5	503.41	491.96	298.4	224.7	219.2	57.4403	-0.312	99.9266	-0.073	4.6622	20.6925	6.6259	0.094	0.977136	977.2550	977.2875	0.000397	39.76	71.38	71.33	119.883
6	504.47	493.01	298.4	225.5	220.3	57.4481	-0.298	99.9426	-0.057	4.6650	20.7817	6.6325	0.132	0.977162	977.2813	977.3134	0.000397	39.76	71.28	71.21	118.492
mv=	**503.66**	**492.15**	**298.4**	**222.5**	**217.5**	**57.4357**	**-0.320**	**99.926**	**-0.074**	**4.6627**	**20.710**	**6.6272**	**0.103**	**0.976832**	**977.136**	**977.170**	**0.000396**	**20.00**	**71.54**	**71.50**	**119.383**
w=	1.82	1.92	0.0	13.8	12.0	0.0338	0.059	0.026	0.026	0.0053	0.166	0.0116	0.051	0.000000	0.331	0.330	0.000003	0.03	0.55	0.53	1.616
s=	0.65	0.68	0.0	5.3	4.6	0.0135	0.023	0.009	0.009	0.0019	0.058	0.0040	0.017	0.000137	0.136	0.137	0.000001	0.01	0.21	0.23	0.644

	[m]		β:	0.5
	D_p (20°C):	D_p (T):	d_O (m):	
$\delta p_{1\,noll}$ (kPa)	0.10226	0.102349	0.051175	
0.0246				

$\delta p_{1\,korr}$	q_v	v_D	$T_{slinga\,in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
20.6778	8.39	1.02	71.78	258670	517340	0.60722	0.60516	0.341
20.5907	8.38	1.02	71.66	257809	515618	0.60742	0.60516	0.373
20.6826	8.39	1.02	71.54	257892	515783	0.60725	0.60516	0.345
20.7351	8.40	1.02	71.30	257448	514896	0.60733	0.60517	0.357
20.6679	8.39	1.02	71.25	256840	513681	0.60727	0.60517	0.348
20.7571	8.41	1.02	71.21	257236	514472	0.60726	0.60517	0.346
20.6852	**8.39**	**1.02**	**71.46**	**257649**	**515298**	**0.60729**	**0.60517**	**0.352**
0.1664	0.03	0.00	0.57	1829	3659	0.00020	0.00001	0.032
0.0582	0.01	0.00	0.24	631	1262	0.00007	0.00000	0.012

Figure 90 – Calibration measurement at Re = 250 000 (70 °C)

$I_{min=}$	4.00 mA	4.00 mA
$I_{max=}$	20.00 mA	20.00 mA
$q_{min=}$	0.00 kPa	0.00 kg/min
$q_{max=}$	500.00 kPa	3000.00 kg/min

p/l= **57.62** p/kg= **100.00**

			VM4	slinga in	slinga ut	E o H		RMV3 puls		DPt		RMV3 mA						VM4	master 1	slinga ut	
No.	q_{vner}	$q_{m\,T,p\,sl\,in}$	p_U	$p_{slinga\,in}$	$p_{slingan\,ut}$	K_1	$felv_1$	K_2	felv2	$\delta p_{1\,brutto}$	$\delta p_{1\,brutto}$	I_{2medel}	$felv_{I2}$	$\rho_{slingan\,in}$	$\rho(T_{sl\,in},p_{sl\,in})$	$\rho(T_O,p_U)$	$\mu(T_O,p_U)$	T_{VM4}	$T_{master\,1}$	$T_{slinga\,ut}$	t_{gate}
	l/min	**kg/min**	**kPa**	**kPa**	**kPa**	**p/l**	**%**	**p/kg**	**%**	**mA**	**kPa**	**mA**	**%**	**kg/dm³**	**kg/m³**	**kg/m³**	**Pa*s**	**°C**	**°C**	**°C**	**s**
1	784.49	767.12	298.4	205.4	196.2	57.3933	-0.393	99.9743	-0.026	5.6087	50.2729	8.0922	0.035	0.977744	977.8539	977.8949	0.000403	39.80	70.24	70.22	76.202
2	784.40	767.06	298.4	205.6	196.4	57.4283	-0.333	99.9803	-0.020	5.6103	50.3229	8.0954	0.121	0.977776	977.8860	977.9268	0.000403	39.80	70.18	70.21	76.962
3	785.11	767.77	298.4	205.4	196.7	57.4184	-0.350	99.9730	-0.027	5.6124	50.3882	8.0957	0.034	0.977809	977.9188	977.9597	0.000404	39.80	70.12	70.20	76.731
4	786.52	769.22	298.4	194.1	187.2	57.4090	-0.366	99.9753	-0.025	5.6195	50.6090	8.1039	0.044	0.977907	978.0120	978.0579	0.000404	39.80	69.95	69.98	76.596
5	783.31	766.13	298.4	204.8	195.8	57.4276	-0.334	99.9810	-0.019	5.6067	50.2081	8.0869	0.031	0.977963	978.0722	978.1134	0.000405	39.81	69.85	69.96	77.040
6	784.71	767.53	298.4	205.4	196.7	57.4163	-0.353	99.9923	-0.008	5.6105	50.3289	8.0954	0.058	0.977998	978.1076	978.1485	0.000405	39.80	69.78	69.92	76.172
mv=	**784.76**	**767.47**	**298.4**	**203.4**	**194.8**	**57.4155**	**-0.355**	**99.979**	**-0.021**	**5.6114**	**50.355**	**8.0949**	**0.054**	**0.977744**	**977.975**	**978.017**	**0.000404**	**20.00**	**70.02**	**70.08**	**76.617**
w=	3.21	3.09	0.0	11.5	9.5	0.0350	0.061	0.019	0.019	0.0128	0.401	0.0170	0.089	0.000000	0.254	0.254	0.000002	0.01	0.46	0.29	0.868
s=	1.05	1.02	0.0	4.6	3.7	0.0131	0.023	0.007	0.007	0.0044	0.138	0.0055	0.034	0.000104	0.104	0.104	0.000001	0.00	0.19	0.14	0.369

	[m]		β:	0.5
	D_p (20°C):	D_p (T):	d_O (m):	
$\delta p_{1\,noll}$ (kPa)	0.10226	0.102347	0.051173	
0.0310				

$\delta p_{1\,korr}$	q_v	v_D	$T_{slinga\,in}$	Re_D	Re_d	C_{act1}	C_{teor}	$felv_l$
kPa	**l/s**	**m/s**	**°C**					**%**
50.2420	13.07	1.59	70.20	394789	789578	0.60719	0.60463	0.423
50.2919	13.07	1.59	70.14	394457	788915	0.60683	0.60463	0.363
50.3572	13.09	1.59	70.08	394513	789026	0.60699	0.60463	0.390
50.5780	13.11	1.59	69.91	394331	788662	0.60678	0.60463	0.355
50.1771	13.06	1.59	69.81	392223	784445	0.60673	0.60464	0.347
50.2979	13.08	1.59	69.75	392605	785211	0.60710	0.60464	0.407
50.3240	**13.08**	**1.59**	**69.98**	**393820**	**787639**	**0.60694**	**0.60463**	**0.381**
0.4009	0.05	0.01	0.44	2567	5133	0.00045	0.00001	0.076
0.1383	0.02	0.00	0.18	1106	2212	0.00018	0.00000	0.030

Figure 91 – Calibration measurement at Re = 400 000 (70 °C)

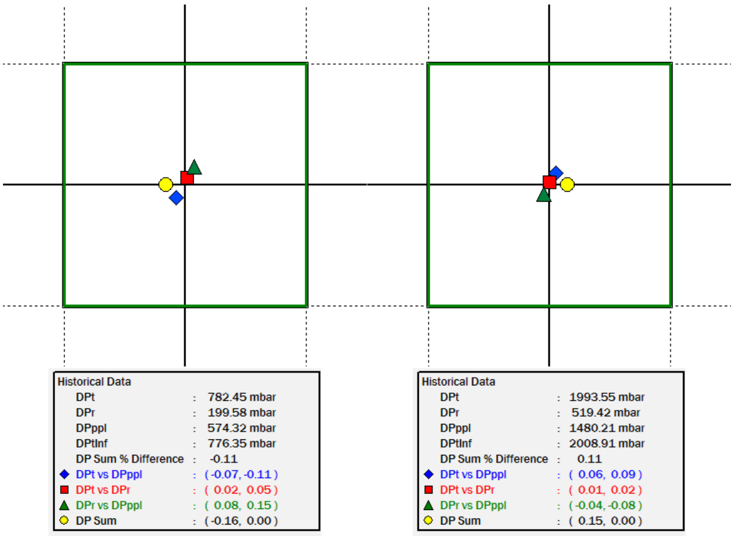


Figure 92 – Snapshot from the test at 30 ˚C (right: Re = 250 000; left: Re = 400 000)

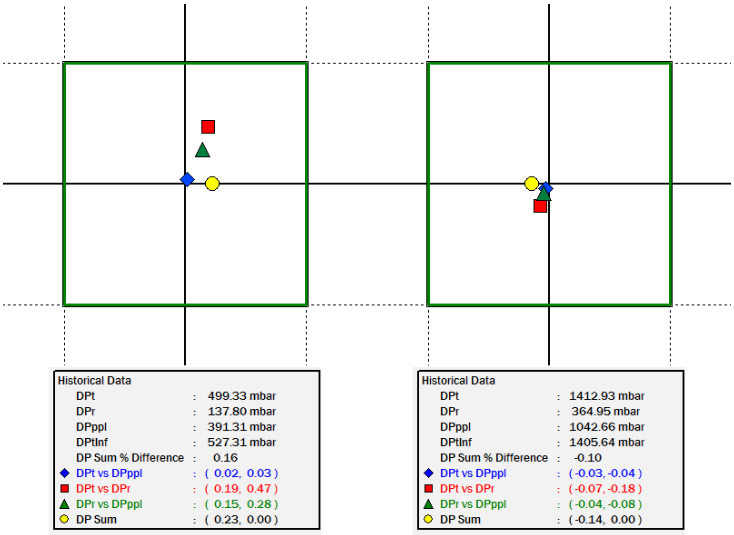


Figure 93 – Snapshot from the test at 40 ˚C (right: Re = 250 00; left: Re = 400 000)

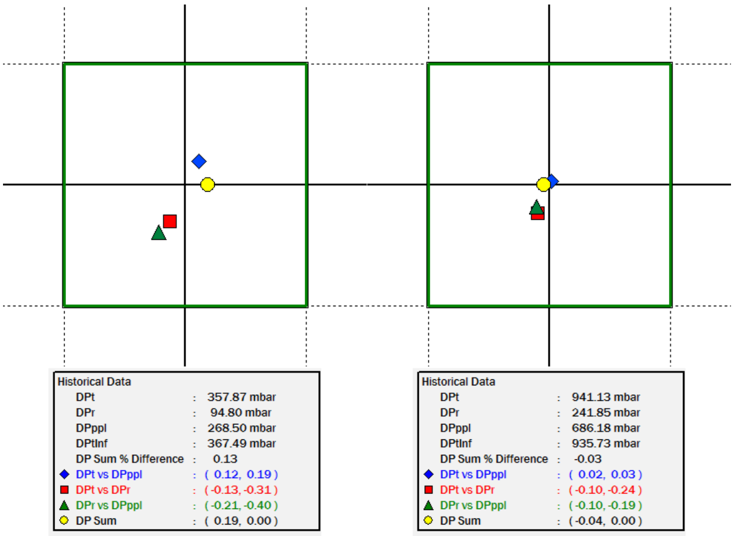


Figure 94 – Snapshot from the test at 50 ˚C (right: Re = 250 000; left: Re = 400 000)

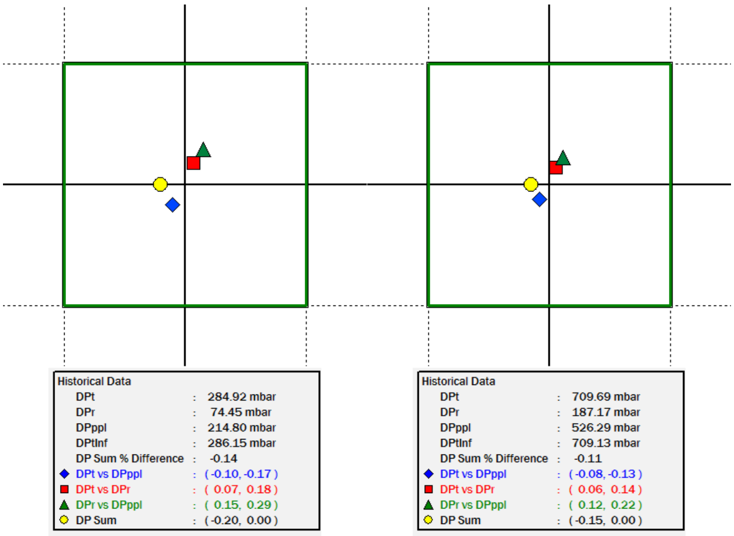


Figure 95 – Snapshot from the test at 60 ˚C (right: Re = 250 000; left: Re = 400 000)

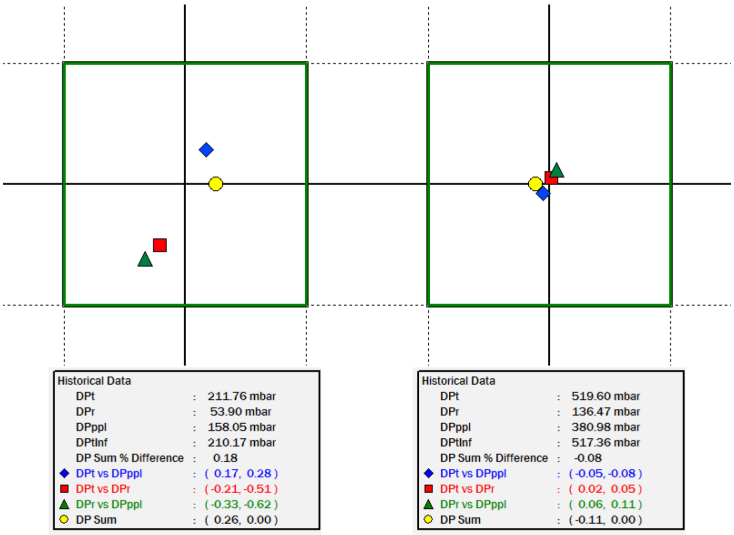


Figure 96 – Snapshot from the test at 70 ˚C (right: Re = 250 000; left: Re = 400 000)

As a result it can be seen from the following diagram the results with an offset of approximately 0.5 % to 0.6 % for the investigated Re numbers of 250 000 and 400 000. These results are in good agreement with the results from Test no.1 (see Figure 23).

It can also been seen that the results (as predicted) are dependent on the Re number. That means calibration measurements on the same Re number results in the same discharge coefficient. This is especially valid for higher Re numbers.

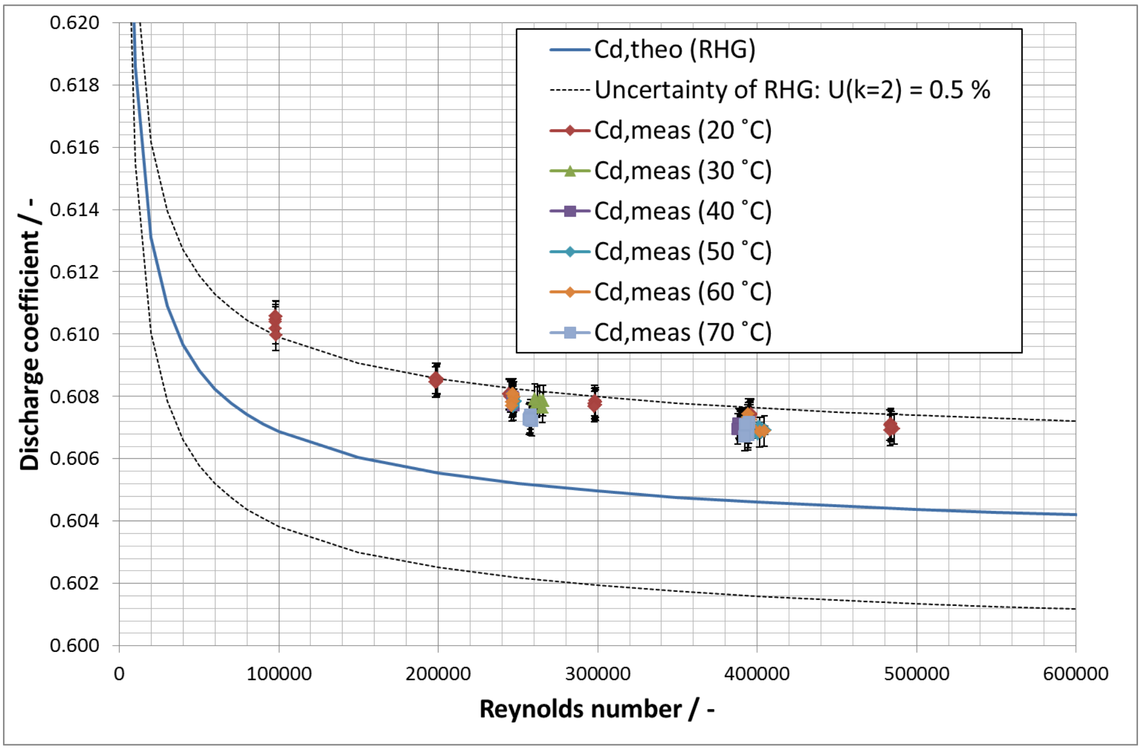


Figure 97 – Results of the calibration measurements (measured discharge coefficient as function of the Re number in comparison with the theoretical values according to the RHG equation) at different temperatures

Result: No significant change was observed in the PROGNOSIS response with the temperature changing from 20 ˚C to 70 ˚C.

The orifice flow rate reported by PROGNOSIS agreed with the reference meter within 0.5 % at each test point.

NOTE: It should be noted that for the measurements at Re = 250000 (especially for the high temperatures with very low pressure difference values) the PROGNOSIS response was unsteady and showed in irregular intervals 'on and off' DP integrity alarm, regardless of the test.

This was attributed to the DP-transmitter since it is known that DP-transmitter work somewhat worse in the lower measuring range. Due to the very low pressure differences at lower Re numbers and resulting very low current output signals the DP-transmitter show a little unsteady behaviour.

4.12. Test 12 – Influence of a 'swirled' inlet velocity profile

Objective – determine whether the DUT detects that a swirled inlet velocity profile is present
Criteria – DUT should react in accordance with the manufacturers' specifications.

- *a) Test at Re = 400 000 at a temperature of 20 ˚C*
- *b) Test at Re = 350 000 at a temperature of 20 ˚C*
- *c) Test at Re = 300 000 at a temperature of 20 ˚C*
- *d) Test at Re = 250 000 at a temperature of 20 ˚C*
- *e) Test at Re = 200 000 at a temperature of 20 ˚C*
- *f) Test at Re = 100 000 at a temperature of 20 ˚C*

Installation of a 'swirl-generator' 12 D upstream of the Orifice plate

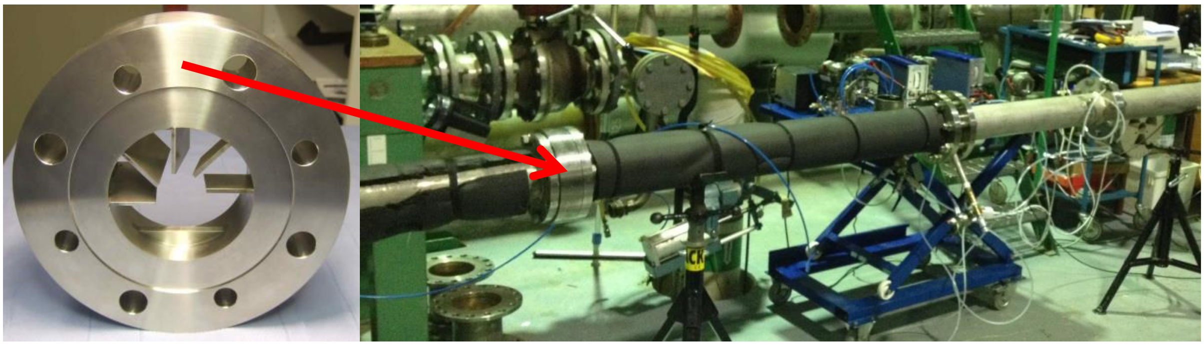


Figure 98 – Left: flow disturber 'swirl-generator'; Right: Installation position (12 D upstream of the Orifice plate)

The flow disturber (see Figure 98) was developed by PTB [8] on the basis of fluid dynamic considerations and allows the generation of a velocity disturbance that is similar to the flow behind a double bend out of plane.

a) Test at Re = 400 000, 4 barG pressure and at a temperature of 20 ˚C

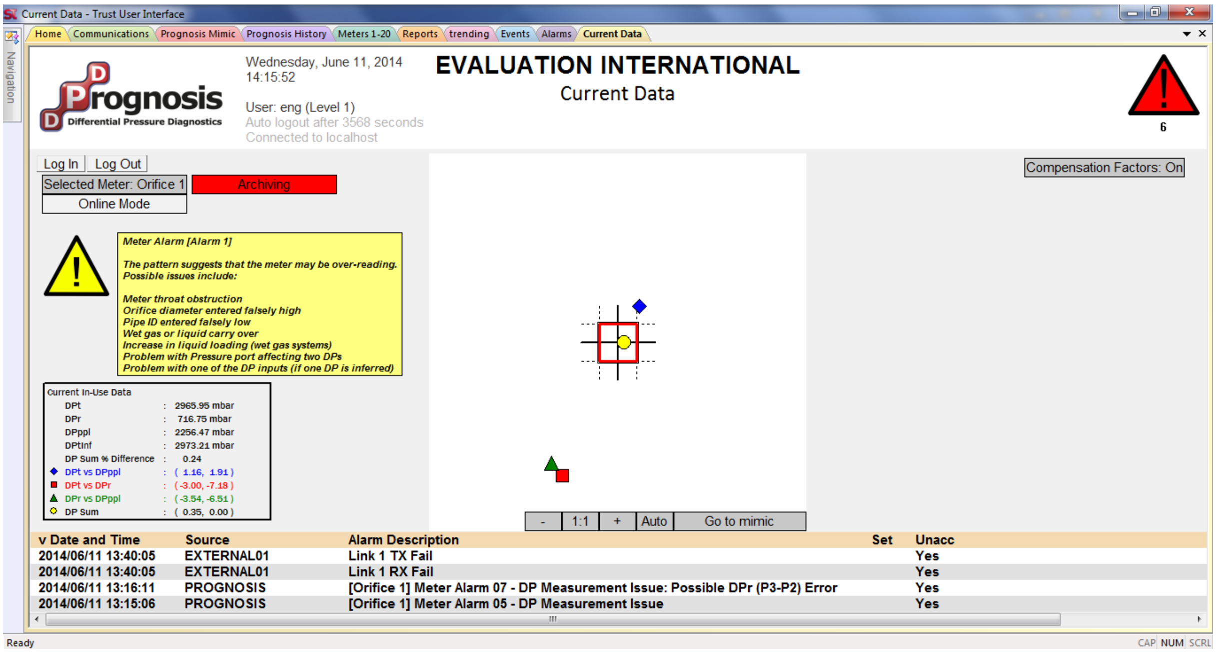


Figure 99 – Snapshot of the test at Re = 400 000 (20 ˚C)

It was observed that the reported Orifice meter flow rate was lower than the flow rate given by the reference meter by approximately -2.60 %.

b) Test at Re = 350 000, 4 barG pressure and at a temperature of 20 ˚C

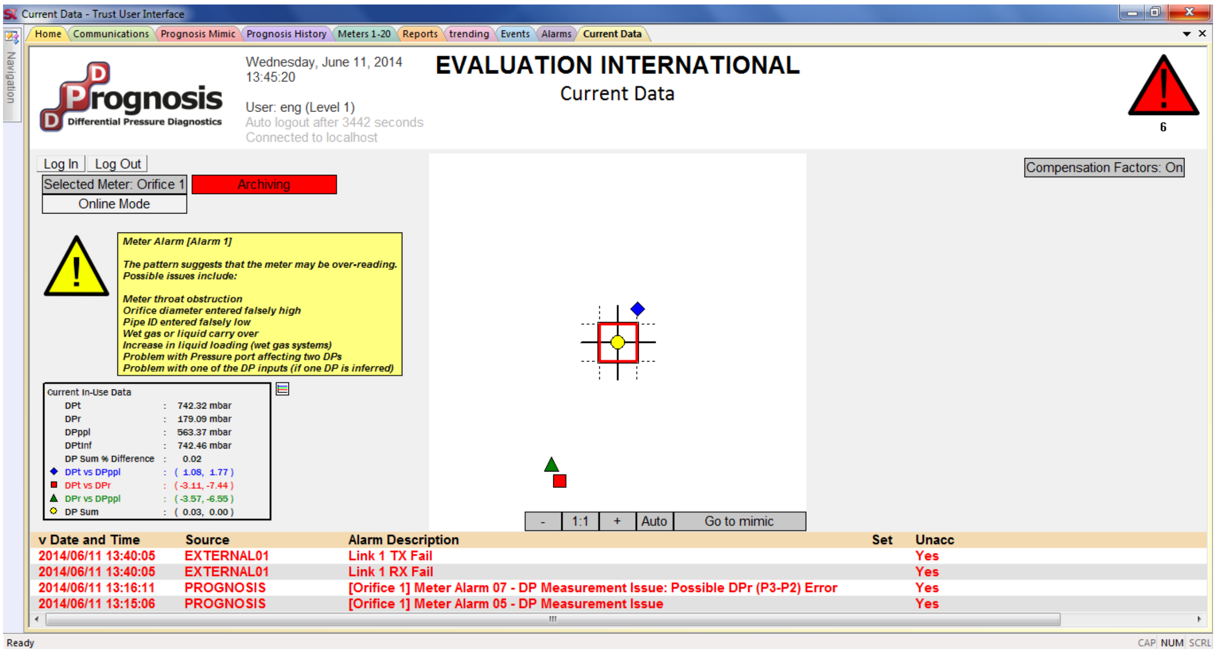


Figure 100 – Snapshot of the test at Re = 350 000 (20 ˚C)

It was observed that the reported Orifice meter flow rate was lower than the flow rate given by the reference meter by approximately -2.50 %.

c) Test at Re = 300 000, 4 barG pressure and at a temperature of 20 ˚C

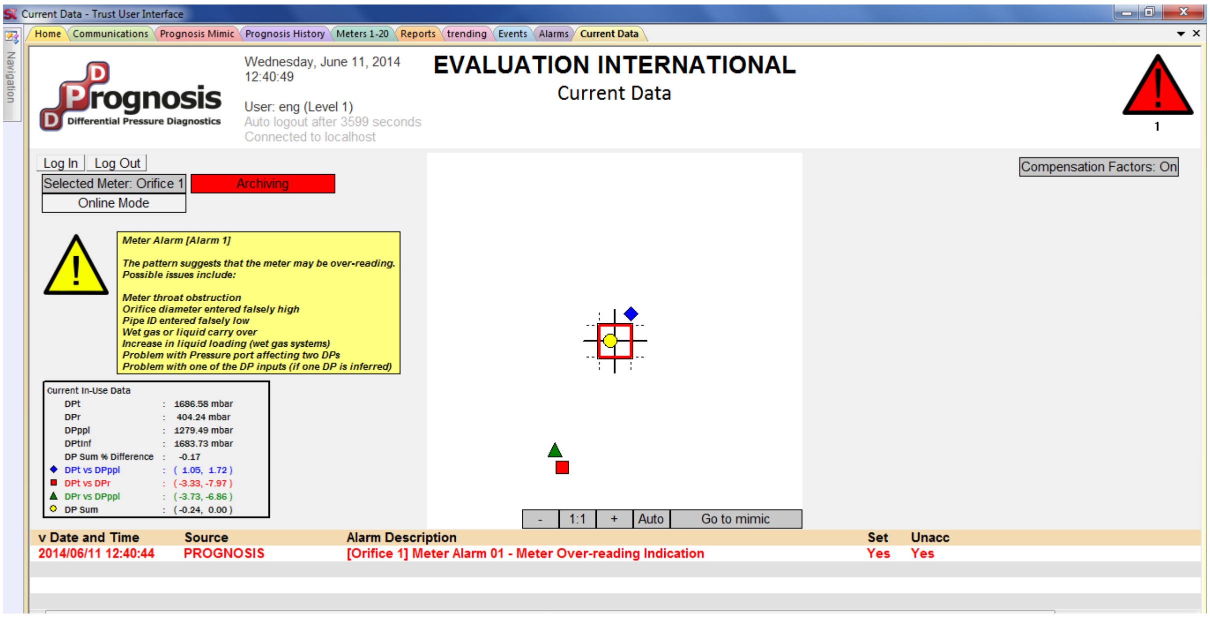


Figure 101 – Snapshot of the test at Re = 300 000 (20 ˚C)

It was observed that the reported Orifice meter flow rate was lower than the flow rate given by the reference meter by approximately -2.45 %.

d) Test at Re = 250 000, 4 barG pressure and at a temperature of 20 ˚C

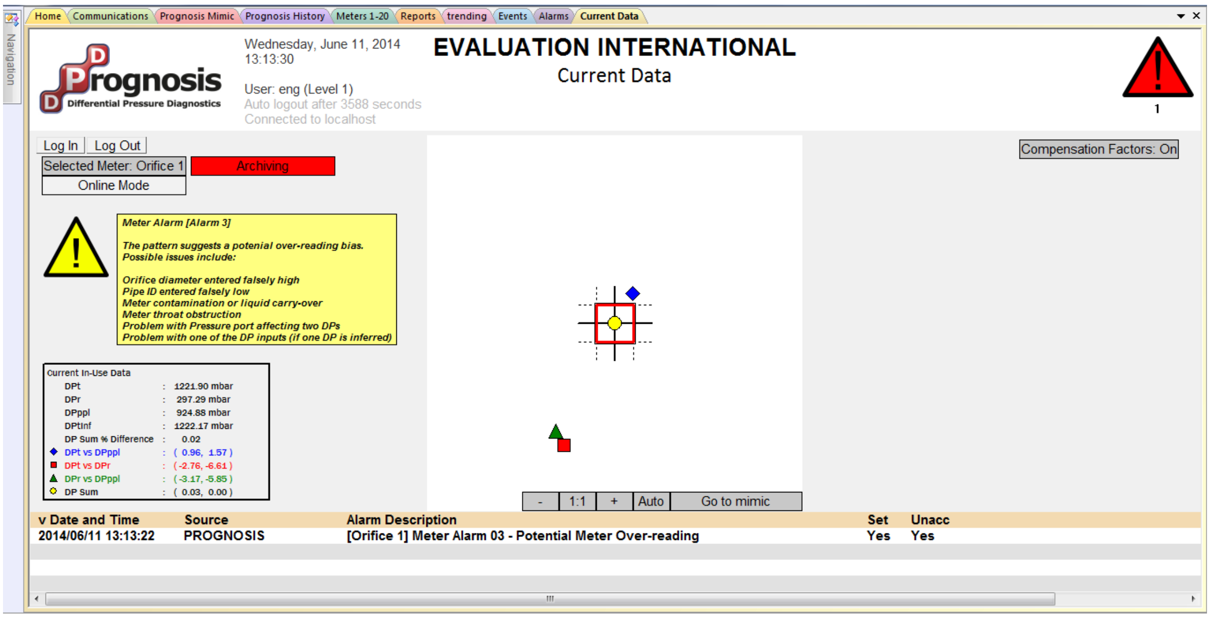


Figure 102 – Snapshot of the test at Re = 250 000 (20 ˚C)

It was observed that the reported Orifice meter flow rate was lower than the flow rate given by the reference meter by approximately -2.30 %.

e) Test at Re = 200 000, 3 barG pressure and at a temperature of 20 ˚C

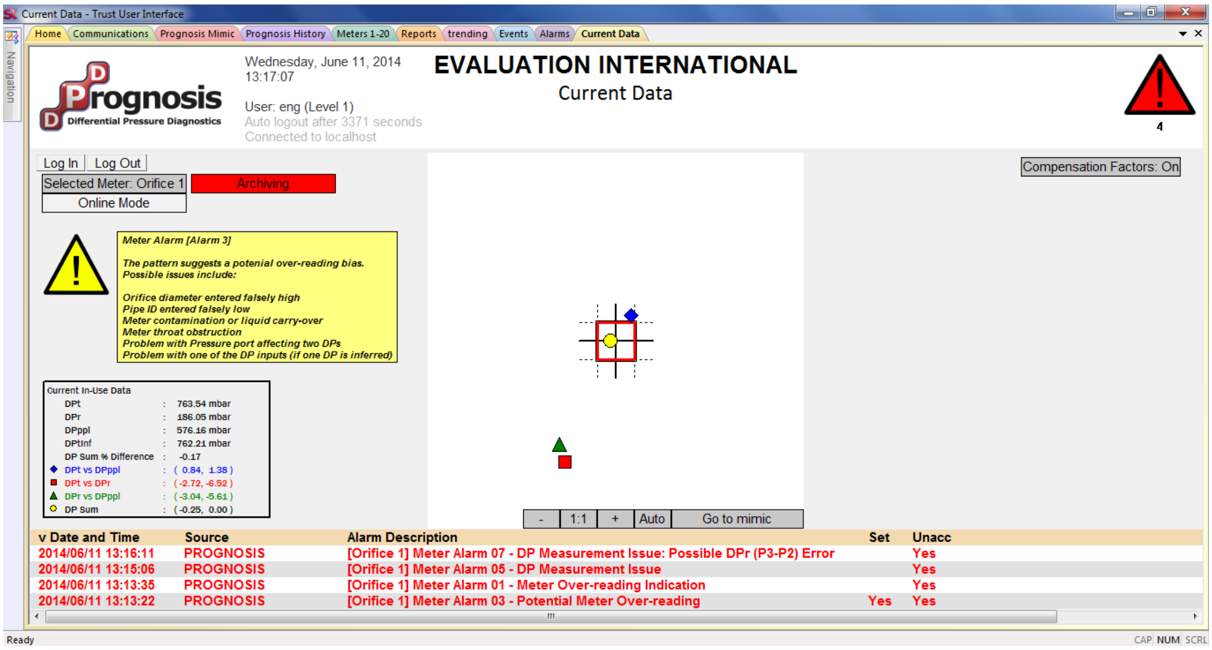


Figure 103 – Snapshot of the test at Re = 200 000 (20 ˚C)

It was observed that the reported Orifice meter flow rate was lower than the flow rate given by the reference meter by approximately -2.15 %.

f) Test at Re = 100 000, 3 barG pressure and at a temperature of 20 ˚C

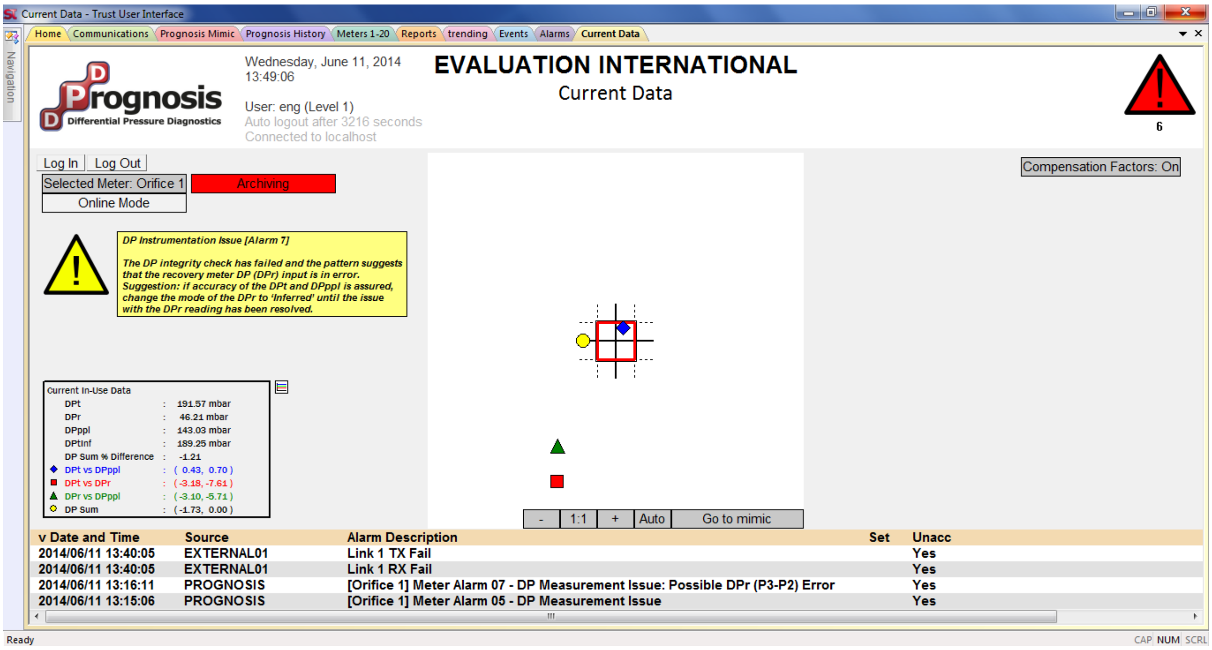


Figure 104 – Snapshot of the test at Re = 100 000 (20 ˚C)

It was observed that the reported Orifice meter flow rate was lower than the flow rate given by the reference meter by approximately -1.80 %.

Result: PROGNOSIS indicated in all cases an alarm due to a potential over-reading bias (expect for test at Re = 100 000 where DP Sum was sometimes also an issue due to the low flow rate).

The reason for the alarm (‘swirled inlet velocity profile’ was not explicitly mentioned in the ‘list of possible causes’.

PROGNOSIS alarm indicated a meter over-reading - but in reality the opposite was the case (under-reading).

NOTE: It was observed that when the flow rate was Re = 200 000 or below, the PROGNOSIS response was sometimes unsteady and showed ‘on and off’ DP integrity alarm, regardless of the test.
This was attributed to the DP-transmitter measurement ranges (0-5 bar for DPt and DPppl; 0-1 bar for DPr) and where possible, tests at 300 000 were performed instead.

4.13. Test 13 – Influence of an asymmetric inlet velocity profile

Objective – determine whether the DUT detects that an asymmetric inlet velocity profile is present
Criteria – DUT should react in accordance with the manufacturers' specifications.

Installation of a 'crescent moon plate' 12 D upstream of the Orifice plate.

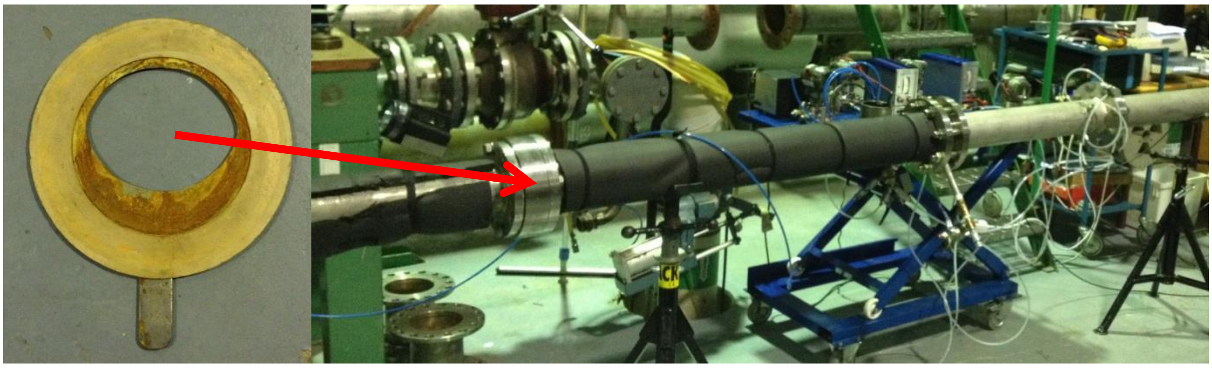


Figure 105 – Left: flow disturber 'half-moon' plate; Right: Installation position (12 D upstream of the Orifice plate)

The flow disturber (see Figure 105) represents a gasket that projects in the fluid flow or alternatively a partly closed ball valve.

a) Test at Re = 400 000 and a temperature of 20 ˚C

A random example showed Orifice flow rate prediction agreeing with reference to -0.12 %.

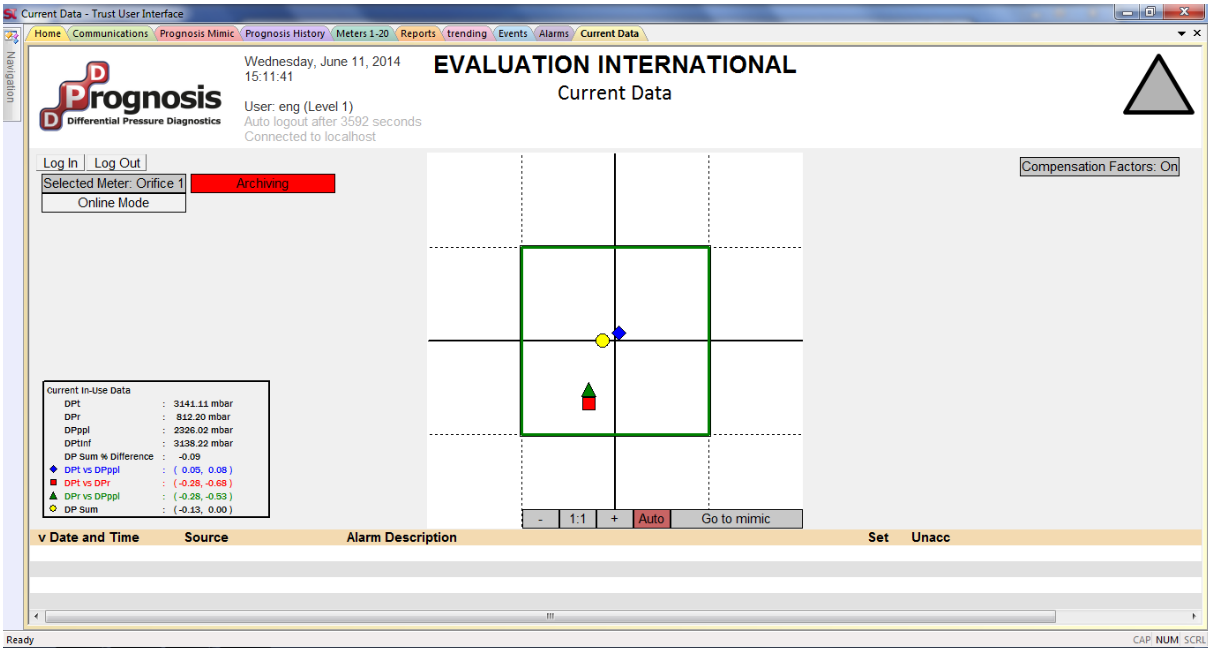


Figure 106 – Snapshot of the test at Re = 400 000 (20 ˚C)

b) Test at Re = 300000 and a temperature of 20 ˚C

A random example showed Orifice flow rate prediction agreeing with reference to 0.03 %.

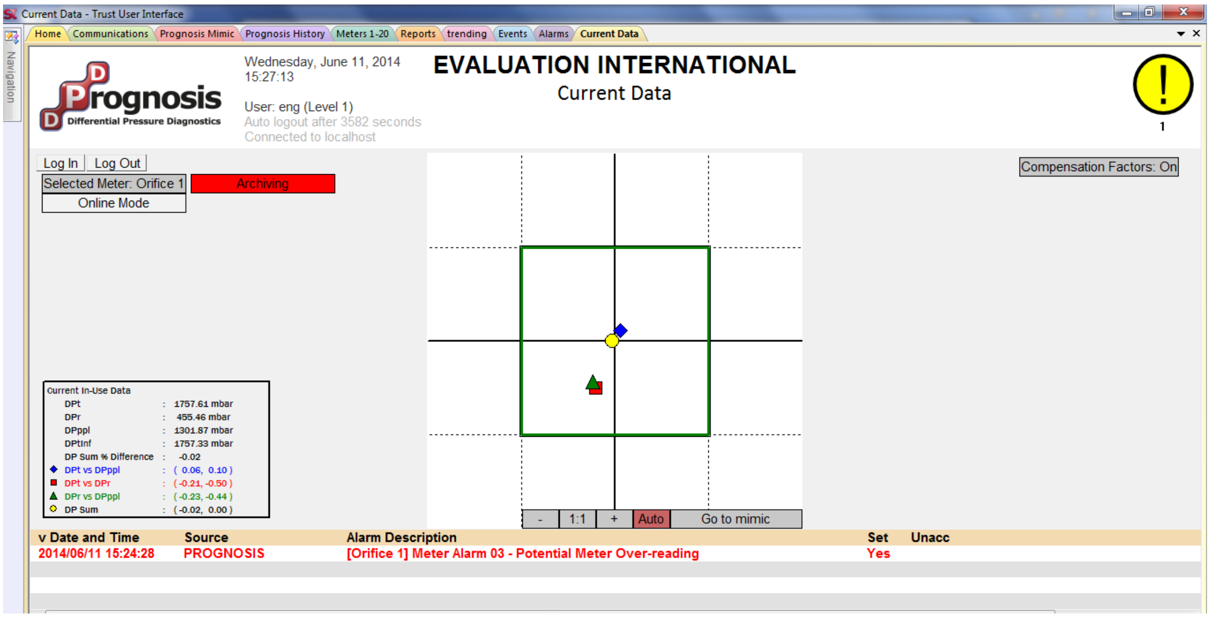


Figure 107 – Snapshot of the test at Re = 300000 (20 ˚C)

c) Test at Re = 250000 and a temperature of 20 ˚C

A random example showed Orifice flow rate prediction agreeing with reference to -0.23 %.

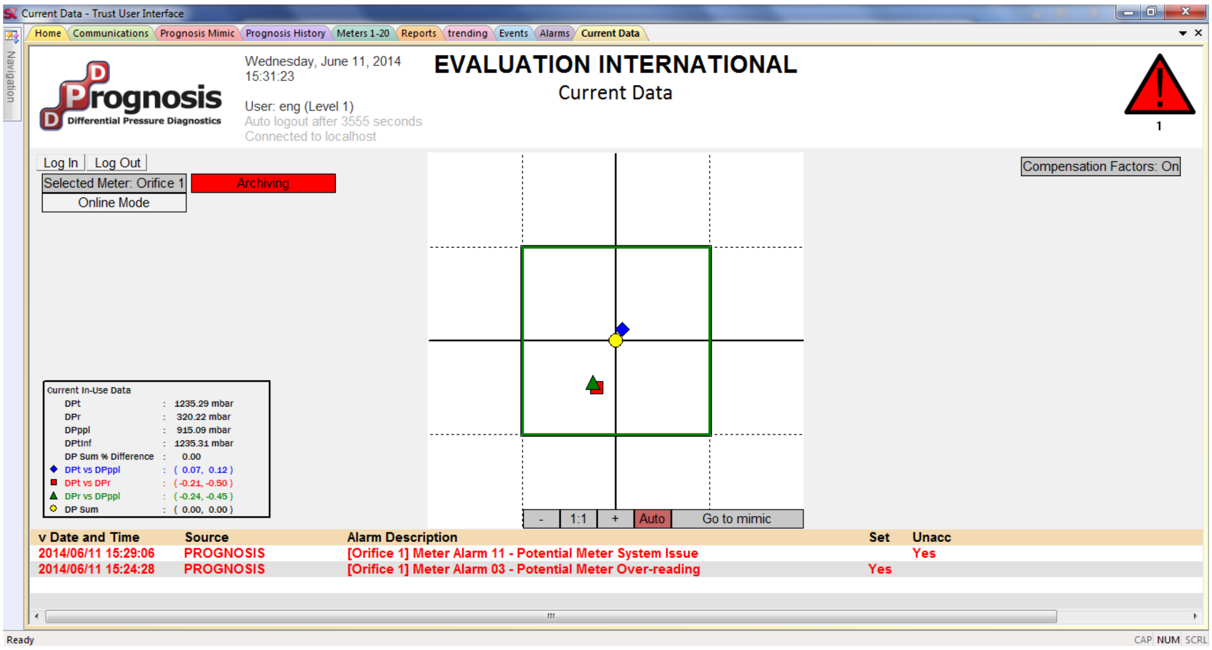


Figure 108 – Snapshot of the test at Re = 250000 (20 ˚C)

d) Test at Re = 200000 and a temperature of 20 ˚C

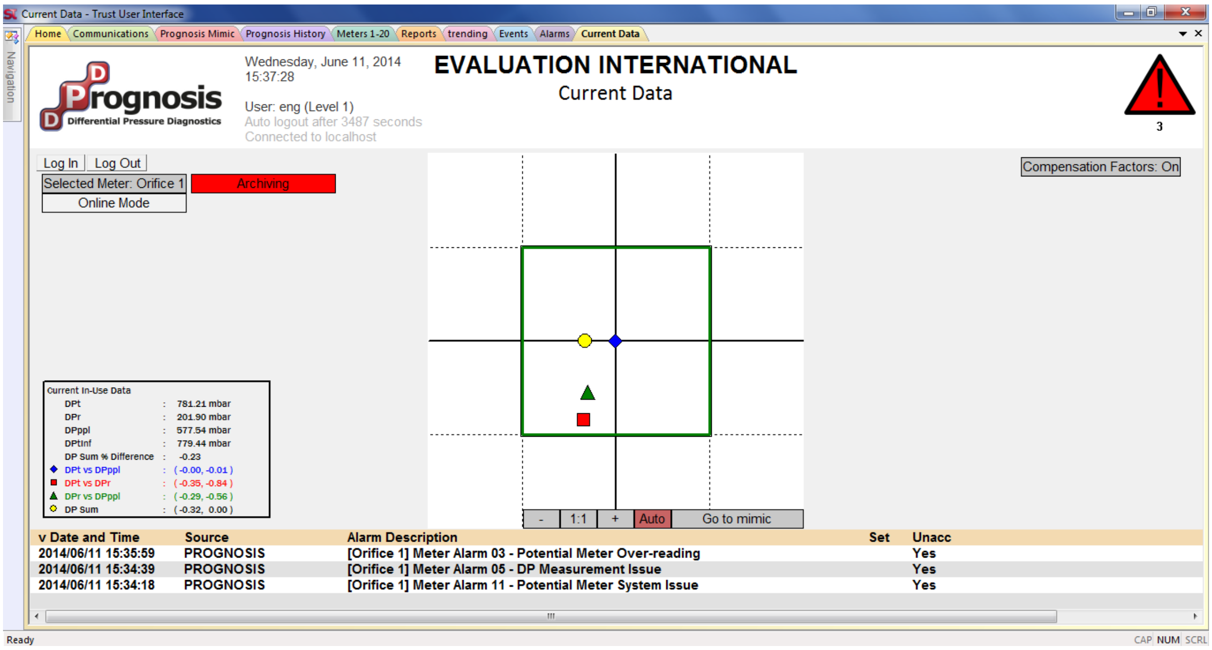


Figure 109 – Snapshot of the test at Re = 200 000 (20 ˚C)

PROGNOSIS responded very similar to higher Re numbers but less stable and in and out of alarm.

e) Test at Re = 100000 and a temperature of 20 ˚C

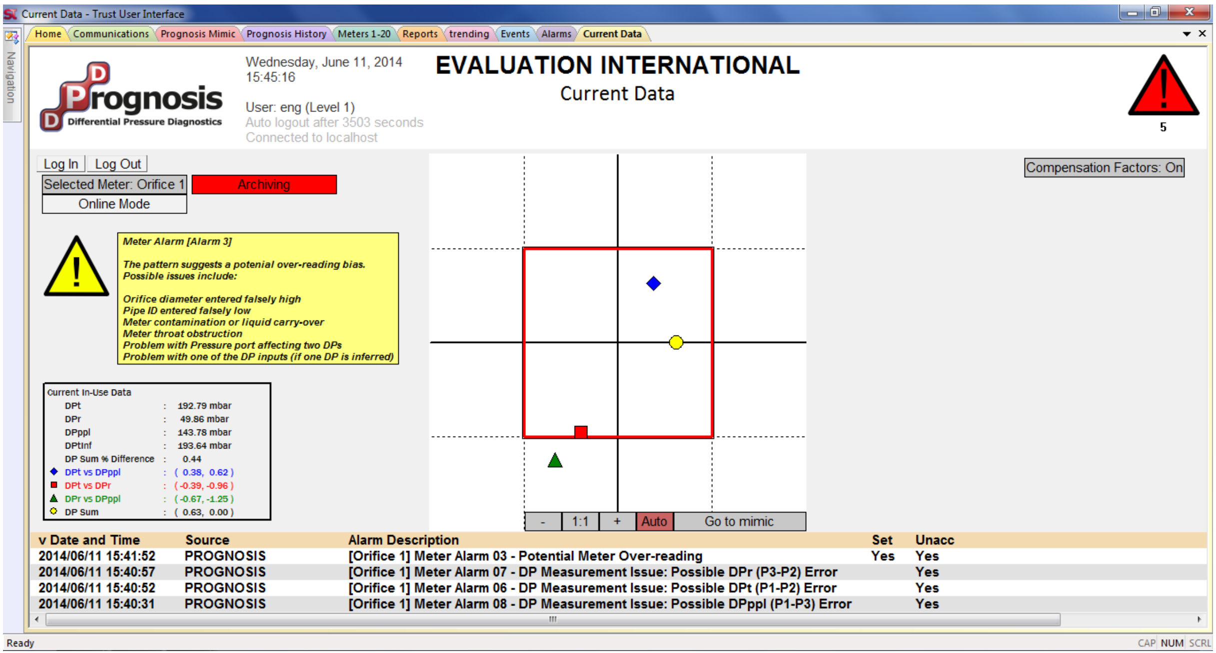


Figure 110 – Snapshot of the test at Re = 100 000 (20 ˚C)

The diagnostic responded very unstable (‘in and out’ of alarm). Still a random example showed Orifice flow rate prediction agreeing with reference to +0.03 %. This response is attributed to the DP measurement integrity being compromised at low Re number.

Result: No significant flow rate bias was observed and hence no PROGNOSIS alarm aside from at very low Reynolds number ('in and out' alarm) where the DP integrity is in question.

It looks like that the disturbance has been largely dispersed within the 12 D and the flow pattern has regressed to normal by the meter inlet.

4.14. Test 14 – Influence of 'multiphase flow' (introduction of air)

Objective – determine whether the DUT detects that compressed air is blown into the pipeline.
Criteria – DUT should react in accordance with the manufacturers' specifications.

a) and b) Test at Re = 300 000 at a temperature of 20 ˚C
c) Test at Re = 100 000 at a temperature of 20 ˚C

Figure 111 – Installation position (at the start of the measuring section) for the adapter with which the compressed air is blown into the pipeline

a) Test at Re = 300 000, 4.5 barG pressure and at a temperature of 20 ˚C
Air pressure: 7 barG

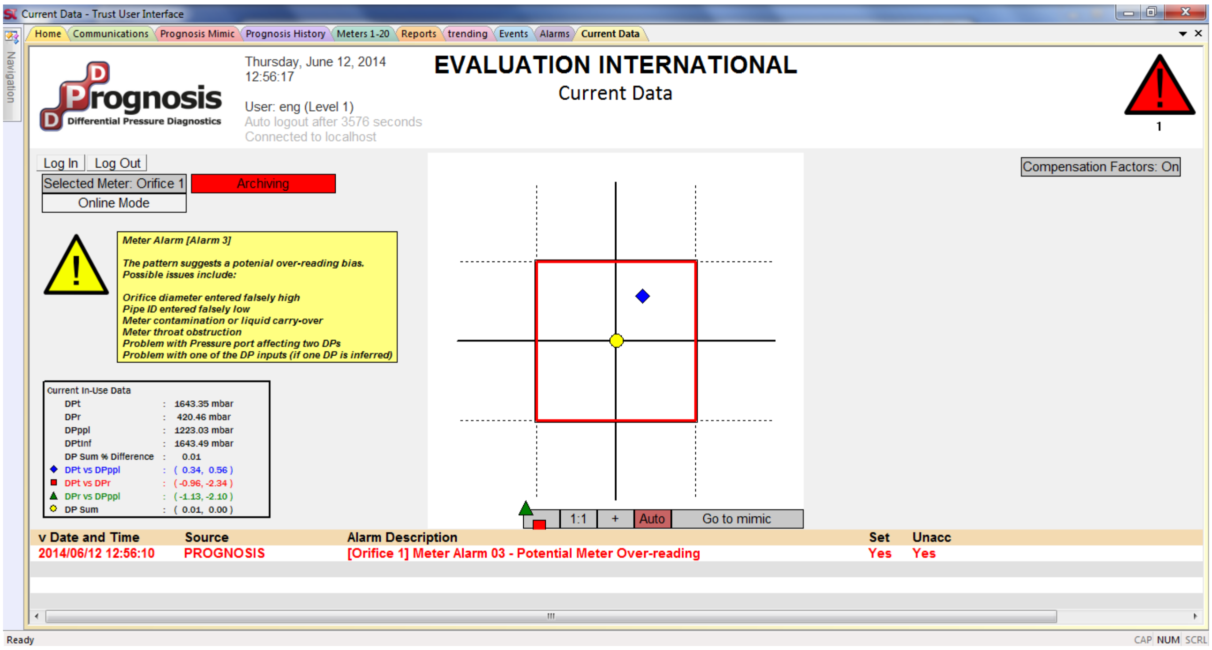


Figure 112 – Snapshot of the test at Re = 300 000 (20 ˚C), air pressure = 7 barG

**b) Test at Re = 300 000, 4.5 barG pressure and at a temperature of 20 ˚C
Air pressure: 5.5 barG**

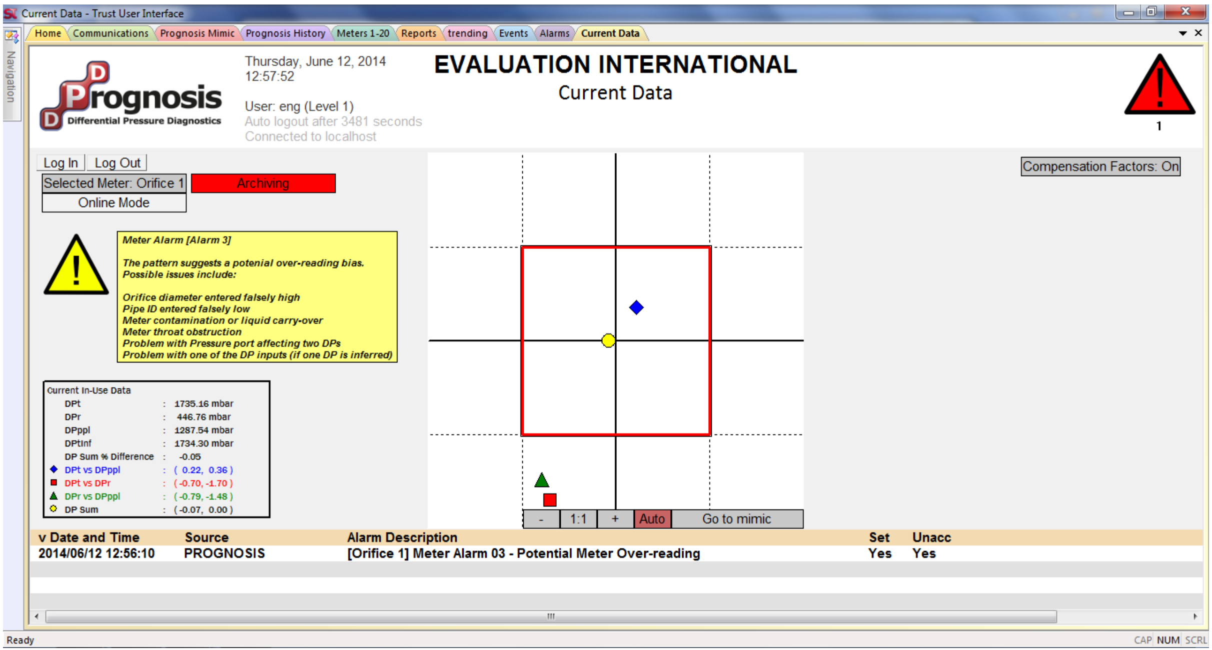


Figure 113 – Snapshot of the test at Re = 300 000 (20 ˚C), air pressure = 5.5 barG

**c) Test at Re = 250 000, 4.0 barG pressure and at a temperature of 20 ˚C
Air pressure: 5.0 barG**

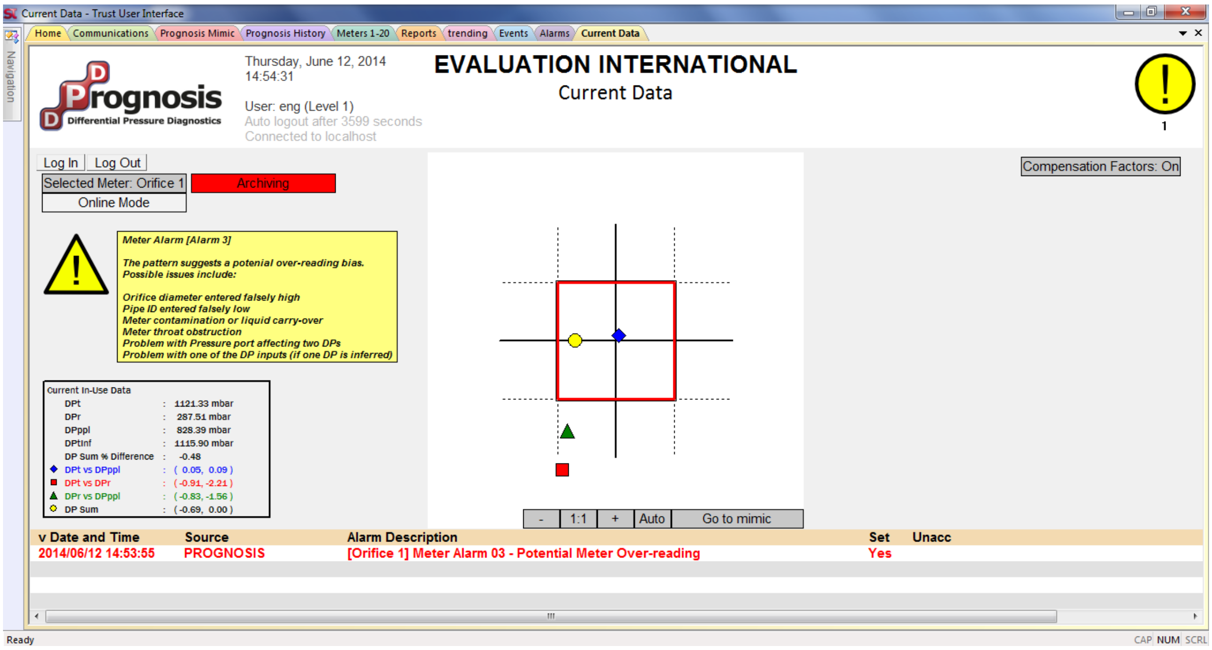


Figure 114 – Snapshot of the test at Re = 250 000 (20 ˚C), air pressure = 5.0 barG

Result: PROGNOSIS indicated in all cases an alarm due to a potential over-reading bias. The reason for the alarm was not explicitly mentioned in the ‘list of possible caused’.

Note: No reliable reference was available, which means the quantity of the introduced air and hence the flow rate prediction error were unknown.

4.15. Test 15 – Backwards installed Orifice plate flow meter

Objective – determine whether the DUT detects that the Orifice plate is installed backwards.
Criteria – DUT should react in accordance with the manufacturers' specifications.

a) Test at Re = 300 000 at a temperature of 20 ˚C
b) Test at Re = 100 000 at a temperature of 20 ˚C

a) Test at Re = 300 000 at a temperature of 20 ˚C

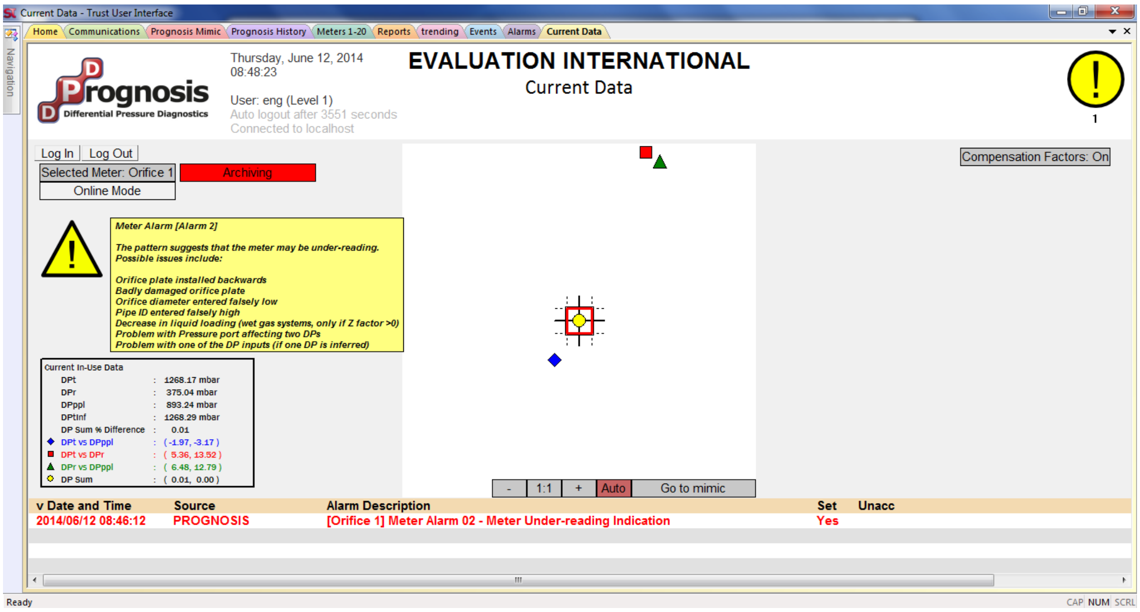


Figure 115 – Snapshot of the test at Re = 300 000 (20 ˚C), backwards installed Orifice plate

b) Test at Re = 100 000 at a temperature of 20 ˚C

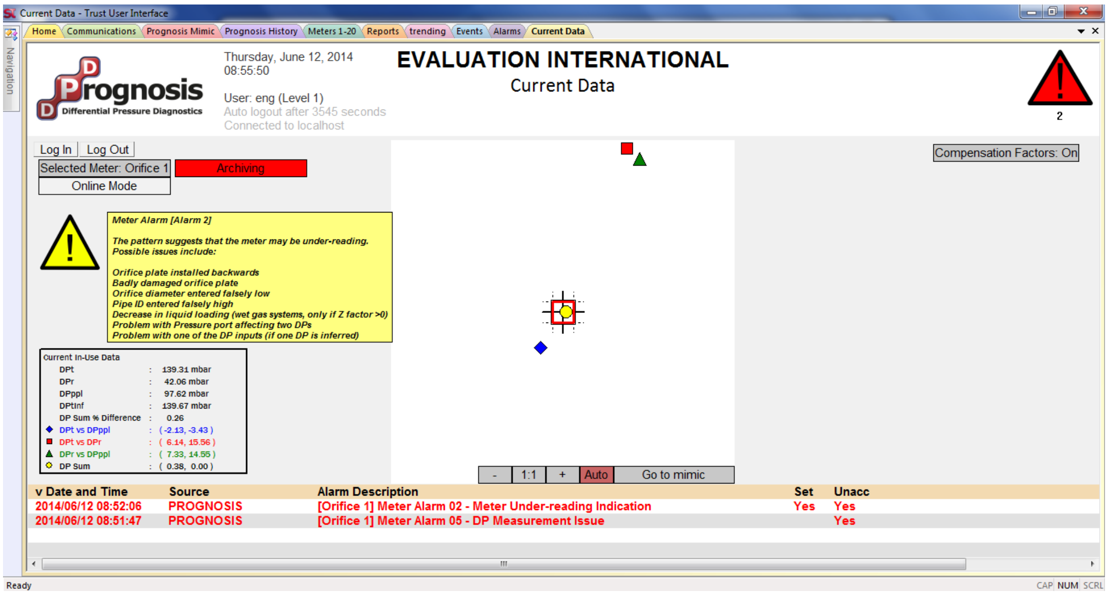


Figure 116 – Snapshot of the test at Re = 100 000 (20 ˚C), backwards installed Orifice plate

Result: In both cases approximately 15 % under-reading was observed and PROGNOSIS gave alarms. One cause of these alarms were displayed as ‘Orifice plate installed backwards’.

4.16. Test 16 – Orifice plate seated incorrectly in the orifice carrier

Objective – determine whether the DUT detects that the Orifice plate seated incorrectly in the carrier
Criteria – DUT should react in accordance with the manufacturers' specifications.

a) *Test at Re = 300000 at a temperature of 20 ˚C*
b) *Test at Re = 100000 at a temperature of 20 ˚C*

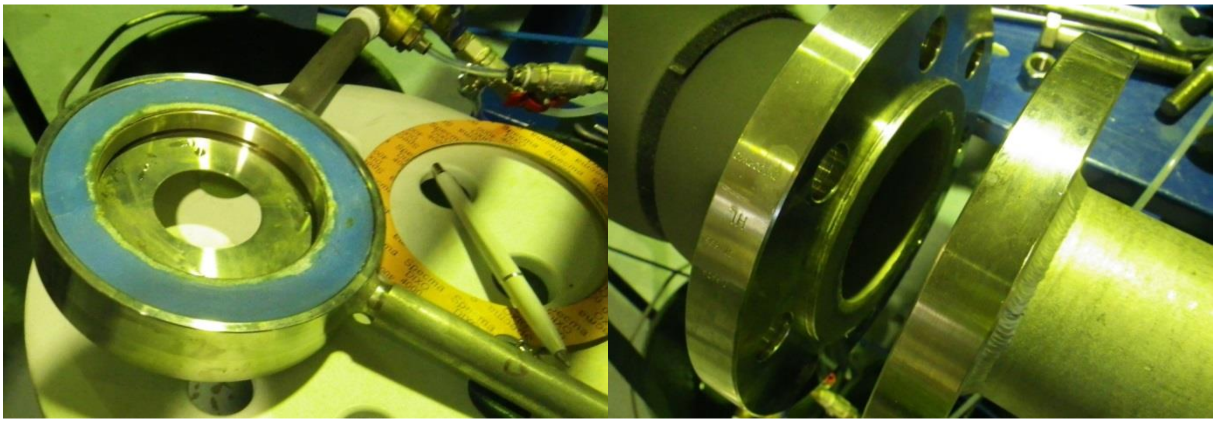


Figure 117 – Left: Orifice plate and indentation as recess for the gasket and the orifice carrier; Right: Orifice carrier which fits exactly in the indentation

With the use of an additional gasket it was possible to misalign the Orifice plate by approx. 5 to 6 mm in the downward direction.

a) Test at Re = 300000 at a temperature of 20 ˚C

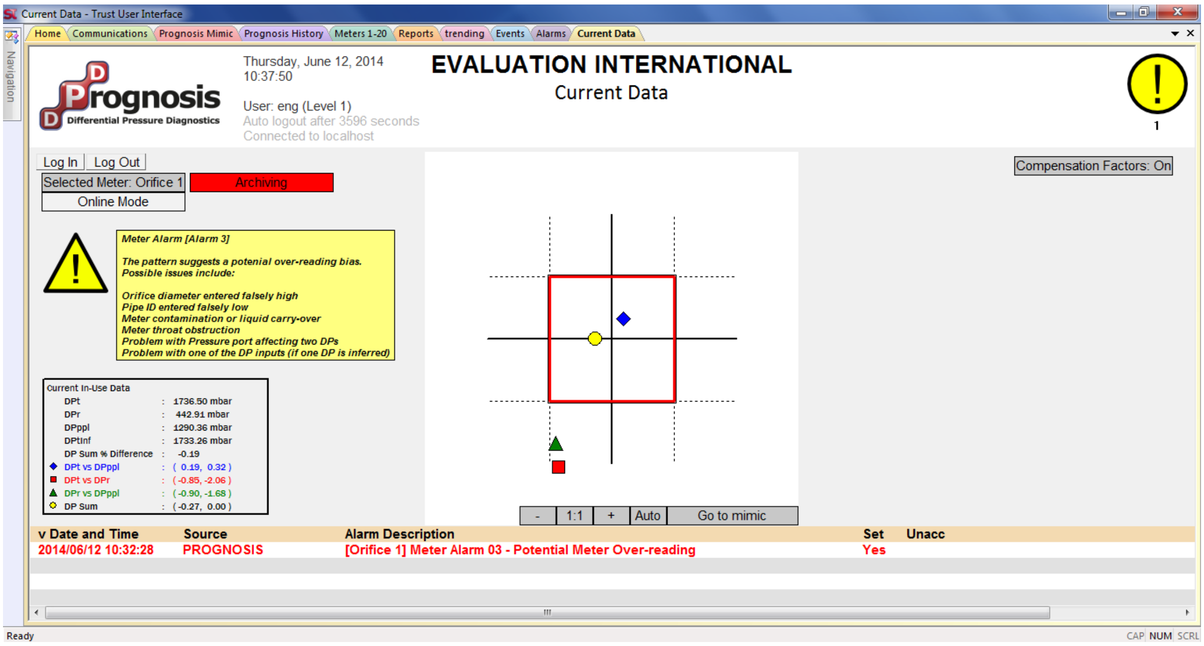


Figure 118 – Snapshot of the test at Re = 300000 (20 ˚C), misalignment of the Orifice plate

b) Test at Re = 100 000 at a temperature of 20 ˚C

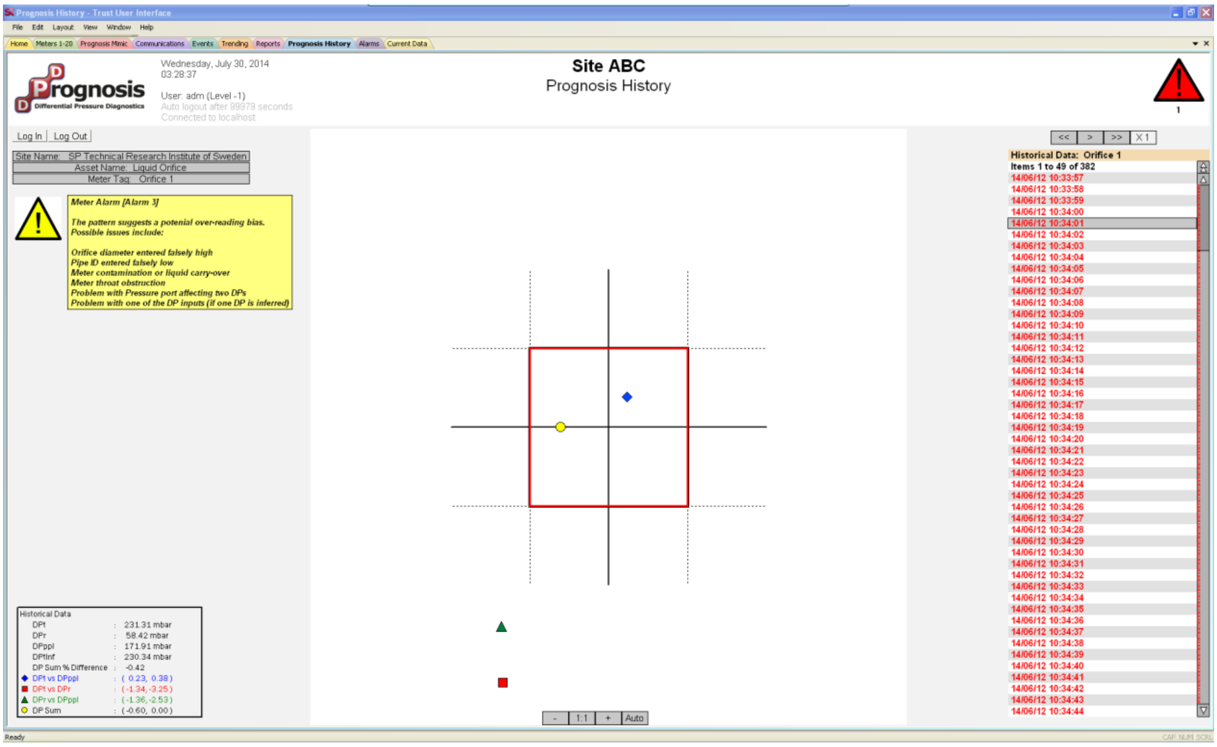


Figure 119 – Snapshot of the test at Re = 100 000 (20 ˚C), misalignment of the Orifice plate

It was observed that the Orifice meter flow rate had a deviation of approximately -3.0 % from the reference meter flow rate at lower flows, and approximately -1.0 % – -1.5 % from the reference meter flow rate at higher flows.

Result: In both cases PROGNOSIS gave alarms due to 'over-reading' of the flow rate. In contrast to that the misalignment of the Orifice plate flow meter leads to an 'under-reading' of the current flow rate.

4.17. Comments and findings concerning the tests and the DUT

a) Comments concerning the tests

In order to cover the entire flow rate range (Re numbers from 100000 to minimum 400000) with only three DP-transmitters in total (1 DPt, 1 DPr and 1 DPppl) each of the three DP-transmitters were selected with the appropriate pressure range. For that reason DP-transmitters with DP-measurement ranges of 0-5 bar (DPt and DPppl) and 0-1 bar (DPr) were chosen.

During the tests it was sometimes observed that for lower flow rates (at temperatures of 20 ˚C and Re = 200000 and below or at temperatures of >20 ˚C and Re = 250000 and below) the PROGNOSIS response was very unsteady and showed (statistically) 'on and off' alarms, regardless of the test.

The reason for this is that the DP-transmitters work in the lower flow rate range (low current output signal) not nearly as good as in the higher flow rate ranges (high current output signal).

A technical solution would be a differential pressure measurement with (each) two DP-transmitters connected in parallel ('stacking' DP-transmitters) e.g. DPt with 0-2 bar and 0-5 bar in order to increase the accuracy for the lower flow rate measurements and to detect possible erroneous measurements.

For this investigation it would mean a much higher effort of time and cost (e.g. more analogue signals, etc.) and the results would not necessarily be more meaningful since all test are more 'responds tests' and absolute accuracy has a lower degree of significance.

b) Comments concerning the DUT

SWINTON CBM system 'PROGNOSIS' is a valuable tool for monitoring DP flow meters in the installation situation (in-situ maintenance) but in case of an alarm the system provides 'only' a number (a selection) of possible causes based on the distribution of the 4 points (DPt vs DPppl, DPt vs DPr, DPr vs DPppl and DPsum).

Different causes of an alarm are often not clearly assigned to a particular reason and lead to a 'shortlist of possible causes'. For instance an incorrectly entered inlet pipe diameter D (a too high value was set) would lead to nearly the same 'normalized plot' as an incorrectly entered Orifice diameter (a too low value was set).

Summarized the PROGNOSIS CBM system can give 'indications' of possible reasons and covers many potential causes but it can happen that a reason for an alarm is not listed in the 'shortlist of causes' but this is the same issue for all diagnostic systems.
There are an infinite number of possible malfunctions and severity of those malfunction combinations. By this fact, it is the nature of all instrument diagnostics that it is impossible to always be able to state which problem exists and what its severity is.
PROGNOSIS clearly shows when a significant malfunction exists. That in itself should be seen as a huge step forward in DP meter flow metering.
PROGNOSIS clearly shows when a malfunction is DP-reading based (always pinpointing the DP-transmitter in question) or based on a problem with the physical meter. That is very useful information e.g. for process monitoring and maintenance.

PROGNOSIS is based on the baseline of the standard ISO 5167.
The equations used in the standard ISO 5167 are only valid for fully developed flow profiles and cannot be applied to disturbed velocity flow profiles (e.g. the Orifice plate flow meter is installed 10 D upstream of a double bend out of plane). (As a side note: For some of these cases the standard ISO 5167 provides tables with additional uncertainties which can be used.)

If PROGNOSIS would be used as monitoring system in such a case PROGNOSIS would detect an alarm. It would then be possible to 'zeroing' the pattern (set a new baseline, see chapter 4.1) in order to monitor for any further changes based on the current installation situation of the Orifice plate flow meter.

In some cases, in particular inaccurate DP or inaccurate meter geometry, as long as this is identified (by the Operator) to be the only issue, then PROGNOSIS can estimate the flow rate prediction error even if the correct DP or meter geometry is not known. (This was illustrated in the write up of all the DP error tests. It was not necessary in the geometry error tests as the correct geometry was known at the time. If it had not been known, PROGNOSIS could be used to find the correct geometry and hence estimate the flow rate prediction error.) In other cases previous testing/experience would be called upon to estimate the error based on the diagnostic response.

A remarkable advantage of PROGNOSIS is that the system also works if the flow rate or the temperature is changing. This means that it is only needed to set the baseline the first time at the start of the condition based monitoring (CBM) system.

5. Test methods, references and definitions

5.1. Test methods

All tests have been made at SP laboratories in Borås, Sweden. Standard type electrical wires and connectors have been used at all tests. All tests were made at an ambient temperature of 20°C ± 3°C. The results in this test report are only valid for the items tested.

5.2. Used reference equipment

All measurements have been made using calibrated instruments.
The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95 %. The standard uncertainty of measurement has been determined in accordance with EAL Publication EA-04/2.

5.3. Definitions

DP	Differential pressure
DUT	Device under test
EI	Evaluation International
Failure	When the DUT does not give the expected response (e.g. a 4 to 20 mA signal within the manufacturer’s specification).
FMEDA	Failure Mode Effect and Diagnostics Analysis
PFD	Probability of Failure on Demand
Reset	DUT returns to normal operation with healthy reading within 5 seconds.
SP	Technical Research Institute of Sweden
ST	SWINTON Technology
TBE	To Be Established by the Test House in the final Evaluation Schedule. Sources of data must include – manufacturer’s claims, international standards, industry good practice, etc.
Test House	The contractor performing the tests

5.4. References

[1] Steven, R. ‘Diagnostic Methodologies for Generic Differential Pressure Flow Meters’, North Sea Flow Measurement Workshop October 2008, St Andrews, Scotland, UK.

[2] International Standard Organisation, ‘Measurement of Fluid Flow by Means of Pressure Differential Devices, Inserted in circular cross section conduits running full’, no. 5167, Part 2, 2003.

[3] Steven, R. “Significantly Improved Capabilities of DP Meter Diagnostic Methodologies”, North Sea Flow Measurement Workshop October 2009, Tønsberg, Norway.

[4] Skelton M. et al, “Diagnostics for Large High Volume Flow Orifice Plate Meters”, North Sea Flow Measurement Workshop October 2010, St Andrews, Scotland, UK.

[5] H. Bettin, F. Spieweck: ‘Die Dichte des Wassers als Funktion der Temperatur nach Einführung der Internationalen Temperaturskala von 1990‘, PTB-Mitteilungen Nr. 3/1990. (German)

[6] M.L. Huber, et al.: ‘New International Formulation for the Viscosity of H_2O’, J. Phys. Chem. Ref. Data, Vol. 38, No. 2, 2009.

[7] ASME MFC-3M ‘Measurement of fluid flow in pipes using orifice, nozzle, and Venturi’, 2004.

[8] Tawackolian K.: ‘Simulation von Strömungsstörungen’
5th Internationale EMATEM-Sommerschule, Kloster Seeon, Germany, 2009. (German)

APPENDICES

Appendix I **Manufacturer’s Safety & Quality Questionnaire**
(15 page document)

Appendix II **Manufacturer's Data Sheet – Standard Prognosis Displays**
(13 page document)

APPENDIX I

Evaluation International
Instrument Evaluation Safety & Quality Questionnaire

To be completed and returned by the Manufacturer within four weeks of receipt

SECTION 1 – Manufacturer's Details

Manufacturer name, address and contact details Swinton Technology Limited Swinton House Hertford Way, York Road Business Park Malton, North Yorkshire YO17 6YG Telephone: +44(0)1653 698844 Email: enquiries@swintontechnology.com Website: http://www.swintontechnology.com

SECTION 2 – General Queries

2 (A)	What ISO 9001 approvals do you have?
ISO 9001:2008 Certificate Number: 021161 Initial certification: 2002 Audited by a UKAS accredited certification service (sira)	

2 (B)	Does your QA scheme cover all aspects of design, manufacture and installation?
Yes	

2 (C)	If your company is part of a corporate organisation, is your QA system subject to, and controlled by, a corporate QA policy?
Swinton Technology (ST) is not part of a corporate organisation.	

2 (D)	Does your QA system cover all activities and products in your manufacturing facility? If not, please specify where it does apply.

The QA system covers all activities and products in our facility.

2 (E)	How many times, and by whom, has your location or company been audited by an external organisation during the last three years?
Sira Certification services has audited the company every year for the last 3 years. FPAL Verify audited the company this year. (FPAL Supplier number: 10048777)	

2 (F)	Who required the audit(s) to be carried out?
The sira audits are part of the normal requirements for ISO9001 and OHSAS 18001 certification. FPAL Verify audit was part of the normal auditing process for suppliers registered with FPAL Verify which is an Oil and Gas Industry Supplier Verification scheme.	

2 (G)	Are (corporate) products, if manufactured elsewhere within your organisation, also subject to an identical QA system?
N/A	

2 (H)	What level of safety certification has been achieved for the instrument and by whom e.g. CE, TUV, CASS, IEC61508? (If none you must also complete Section 3.)
N/A. No instrument is supplied.	

2 (I)	Do you have ISO9000 part 3 accreditation or similar? (If no, you must also complete Section 4.)
No	

APPENDIX I

Evaluation International
Instrument Evaluation Safety & Quality Questionnaire

2 (J)	What independent performance testing has been carried out on this instrument and by whom? (If none, you must also complete Section 3.)

N/A. No instrument is supplied.
However, if we are to consider the Prognosis technology/concept. Independent testing has been performed including the following:
1] Testing by CIATEQ of Prognosis on Orifice meters measuring water at a Mexican Government Water Flow Facility in August 2012. The conclusion of the CIATEQ testing included "Prognosis has the ability to show meter malfunctions occurring in real time, or when reviewing historical archived data, when in the past a malfunction occurred. This then can protect the operator against flow rate mis-measurement and can reduce needless scheduled maintenance."
2] Testing by NEL who used part of the Prognosis concept on Venturi meters measuring heavy oil. The conclusion of the NEL testing included "'Prognosis has been shown by NEL to work extremely well at the very low Reynolds number range, where the discharge coefficient and other diagnostic parameters are highly sensitive to Reynolds number.
The existing Prognosis commercial system, available to industry for the last three years, with no additional features required, allows an operator a good estimation of the viscosity of the heavy oil, the Reynolds number and a good measurement of the mass flow rate. The NEL analysis of the three Prognosis DP ratio diagnostic checks against Reynolds number is confirmation (using new interesting flow data) of prior DP Diagnostic work on the capabilities of Prognosis to aid operators of DP meters."

2 (K)	Is a copy of the associated independent testing reports and/or certification available? (If so please provide.)

In relation to the testing summarised in 2 (J), the following white papers are available in the public domain:

Mocada D., et al "Results Of Testing An Orifice Meter Diagnostic System At A Mexican Government Water Flow Facility" Flomeko Conference, Paris, September 2013.

Marchall C., et al "Prognosis Applied To High Viscosity Flows", South East Asia Hydrocarbon Flow Measurement Conference, March 2014.

2 (L)	What has the field experience been? How many units have been deployed and for how long? What in-field faults have been experienced and what is the in-field fault reporting mechanism? How much relates to the version being assessed and how much to other versions?

ST does not supply field equipment, the Prognosis software is installed on a PC in the safe area. Typically the end user or a third party supplier provides the associated field equipment.
Regarding Prognosis software applications, 20 have been supplied with the oldest being in use for approximately 4 years and with approximately 5 at the pre-installation/commissioning phase. Many of these software applications monitor multiple meters and the applications cover 49 meters altogether. The software used for this assessment is a new version which has been used on 5 of the 20 applications.
If any fault is reported in either the software or the hardware (PC) provided by ST this is entered into ST's Maintenance Database and QA procedures are followed to ensure that any fault is investigated and (where appropriate) rectified by ST engineers.

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2 (M)	What type of programmable device is used? e.g. describe the architecture.
The Prognosis software includes a configuration editor ('Prognosis Editor') which allows the end user to configure communications links and relevant meter-specific settings. The Prognosis Editor is a separate software application to the Prognosis User Interface but shares the same database. Alternatively ST can provide the Prognosis software pre-configured for a specific meter or meters provided relevant information is provided on the metering system application.	

2 (N)	Who produced the software for the device, e.g. in house or out-sourced?
Swinton Technology produced the Prognosis software in-house. The Prognosis software enables the application of the Prognosis technology.	

2 (O)	How long has the instrument been supported? How long will the instrument continue to be supported?
No instrumentation is supplied. See also question 3.11 (A)	

2 (P)	Has the instrument already been used commercially? (If so please list the industries and, if possible, typical clients.)
No instrumentation is supplied. See also question 3.13 (A) To date Prognosis has been supplied in the Oil and Gas industry. Typical clients are end users (oil and gas Operators) as well as skid vendors and metering computer system integrators.	

2 (Q)	Does a hardware & firmware FMEDA exist? (If so, please provide a copy). What is the postulated MTBF, SFF and diagnostic coverage?
N/A	

2 (R)	Do you have customer statements from previous users? (If so please provide.)

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"It works!!! It looks like the prognosis indicator for liquids is indeed correct!!!" Ben Glover, Centrica Energy. "Perenco UK has adopted the Prognosis technology for monitoring dry gas Orifice meter systems. I find the daily report very useful (which is emailed automatically) as it provides a summary of any alarms which were raised and how long they were set. Prognosis gives us confidence in the meter system and assurance that no inspection is required. When we have performed inspections the findings have confirmed no issues present, in line with what Prognosis is telling us. Perenco UK is looking to use Prognosis on more meter systems in the North Sea in the future." Michael Horne, Metering Team Leader, Perenco UK. "The observed benefits listed below were observed by the BP CATS operator during the prognosis trails they conducted in 2010 • BP CATS regard Prognosis as a means of assurance that a meter ***<u>does not</u>*** have a problem • Custody transfer orifice meters are currently regularly inspected with routine maintenance. A system showing that the meter is OK, saves on needless maintenance • Besides the cost saving this also reduces the quantity of gas released to the environment & personnel exposure to the dangers of the high pressure system" Mark Skelton, BP.

2 (S)	What are your warranty conditions?
Typically 12 months warranty will be provided on software from the time of delivery to site, however ST can offer extended warranty periods upon request. If hardware (a PC) is also provided, the warranty period is also typically 12 months however up to 3 years warranty can be provided upon request depending on the warranty conditions of the PC manufacturer.	

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SECTION 3 – Specific Questions related to Client Specific Programmable System Assessment Procedure

Section 3.1

3.1 (A)	What is the method for ensuring that data passed over communication links is not corrupted?
All communications messages include a checksum. For Modbus RTU communications, this is a 16-bit CRC, for Modbus ASCII it is an 8 bit LRC. For Modbus/TCP it uses the underlying TCP checksums.	

3.1 (B)	What self-test features are provided?
All running tasks are monitored internally by a watchdog service. Applications will be restarted on fail. The event log will show any task failures and restarts.	

3.1 (C)	What memory checks are performed to detect corrupted code or data storage?
The Windows PC on which the Prognosis software is installed performs memory checks on start up.	

3.1 (D)	Are the communications links electrically isolated?
N/A This relates to hardware which is not supplied by ST.	

3.1 (E)	What other self-diagnostics are used?
See 3.1(B) In addition, the status of communications links is monitored continuously and displayed clearly in the software user interface. An alarm is raised in the software is a communications link failure occurs. All data inputs acquired externally (via a communications link) are clearly visible and updated in real time in the software user interface.	

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Section 3.2

3.2 (A)	Are links, switches or some other means used to configure the device? If links are used, are they soldered or wire wrapped?
N/A	

3.2 (B)	Is there separate earthing for analogue and digital circuits?
N/A	

3.2 (C)	What type of memory is used? How is the object code stored? What memory protection is provided?
The software runs on a Windows PC. Object code is stored on disc, memory is standard PC RAM. Windows memory protection is utilised, i.e. applications run in their own protected workspace and the OS ensures that applications cannot corrupt other application workspaces.	

3.2 (D)	What transient suppression is used on the signal output?
N/A This relates to hardware which is not supplied by ST.	

Section 3.3

3.3 (A)	Does the user interface confirm a command has been successfully implemented? What information is provided to the user on failure of the device to indicate that it has failed?
In relation to the Prognosis software, the user interface 'Current Data' display changes in real time (up to once per second) confirming that changes to inputs have been processed. The 'Events' log also clearly displays any changes to the software configuration/settings that have been implemented. If communications fails, an alarm is raised.	

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Section 3.4

3.4 (A)	What configuration management procedures are in place for the software? i.e. list the procedures used to control the production and issue of software versions.
The software comprises several applications. All applications contain a built in version stamp which is automatically generated by version control software. Before a software version is issued for delivery to a customer it is subject to full internal testing against a 'Functional Design Specification' using an 'Acceptance Test Manual'. Both documents are checked and approved by the Prognosis Product Manager.	

3.4 (B)	What checks are carried out between the software installed on the device and the software master copy?
The Prognosis 'product' software is identical to that which has been developed and tested internally. Where Swinton Technology delivers software which has been pre-configured, this software is subject to internal testing of the particular configuration requested by the end user. Where applicable, a bespoke 'Functional Design Specification' and a bespoke 'Acceptance Test manual' is submitted to the Customer for approval prior to internal testing. A completed 'Acceptance Test Manual' is also (if requested) supplied to the Customer as proof that the software is 'fit for purpose' and the Customer is also invited to witness a formal 'Factory Acceptance Test'.	

Section 3.5

3.5 (A)	Is there any undocumented, non-standard or ill-defined feature of the hardware used by the code?
N/A	

Section 3.6

3.6 (A)	What approach to the software design description has been adopted and used? (Top down / bottom up).
A proposed Functional Design Specification document is created by the Prognosis Product Manager in line with Customer feedback, requests and internal testing feedback. This document is assessed by the Software Development Team and is finalised between the Software Development Team and the Prognosis Product Manager prior to software development. For future software releases, the Functional Design Specification is revised and updated and modifications are approved by the Prognosis Product Manager and the Software Development Team prior to software modifications being performed.	

3.6 (B)	How many levels of decomposition of the software design have been used? Is the design

	modular? How many modules are utilised?

The design is modular; a top level summary of modules used:

- Core database code (in a DLL)
- Alarm management
- Background processing
- Report generation
- Data server
- Trending module
- Prognosis application
- Calculation module
- Modbus master module
- Modbus slave module

The system is object orientated (programmed in C++). The top level modules above are all further subdivided into C++ classes each of which uses one source and one header file.

Section 3.7

3.7 (A)	What is the approximate size (lines of code) of each software module?

Some modules are much more complex than others and are split into sub-modules but some examples are:

- Core database code: 80 sub-modules (classes).
- Alarm management: 4 sub-modules (classes)
- Background processing: 4 sub-modules (classes)
- Report generation: 6 sub-modules (classes)
- Data server: 4 sub-modules (classes)
- Trending: 5 sub modules (classes)
- Prognosis application: 8 sub modules (classes)
- Calculation module: 48 sub modules (classes)
- Modbus master module: 9 sub modules (classes)
- Modbus slave module: 4 sub modules (classes)

Class file sizes vary but 300 lines is an estimated average.

Section 3.8

3.8 (A)	How much re-use of software has there been? What is the pedigree of the re-used software? How was any re-used software demonstrated to be correct in the previous application and to also be suitable and correct for the revised application, i.e. what level of testing was carried out?

Where the Prognosis Product Software is modified either for a bespoke application or for a next formal release, the modifications and any functionality affected by the modifications are subject to formal in house testing against a Functional Design Specification and using an Acceptance Test Manual. Any specific applications which have not been modified for the new software release are subject to spot checks and 'sanity checks'.

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3.8 (B)	Are you aware of licence cut off dates, etc. which could affect software operation?
This is only relevant to Microsoft Operating Environments. ST is aware of obsolescence dates.	

Section 3.9

3.9 (A)	What software fault reporting and corrective action mechanism is in place? State your procedure number.
If any fault is observed or any suggestions for improvement are noted during formal testing, these are raised as 'System Performance Reports' (SPRs) on ST's internal Management Information System (MIS). The software development team and the Prognosis Product Manager review these SPRs regularly and the software is not approved for issue until all SPRs have been addressed. Where improvements to the software are noted but are not considered urgent, they are added to a list of future developments which are reviewed and prioritised by the Prognosis Product Manager.	

Section 3.10

3.10 (A)	What coding standard, methods (ISO, Waterfall, etc) and support tools (System Architect, etc) have been used for the software produced? Who produced the software (Internal / External)?
ST uses an in-house coding standard. All software is managed by Microsoft Developer Studio 2010	

Section 3.11

3.11 (A)	How long will the device be supported?
Extended support contracts are available for all hardware/software provided by ST.	

Section 3.12

3.12 (A)	Is there any mechanism for the checking of versions between software components / modules?

All applications contain a built in version stamp which is automatically generated by our version control software. This stamp is viewable on the user interface.

3.12 (B)	What security measures are provided to prevent unauthorised changes to software and configuration?
All of the software which makes up the Prognosis applications is managed using the CVS (Concurrent Version System) version control system. This system holds a 'repository' of software on Swinton Technology's server. This repository is the central holding point for every version of Prognosis software. It is backed up daily as part of the routine server backup system. In order to work on the Prognosis code, the engineer performs a 'cvs checkout' using a uniqe user name which extracts the code out of CVS onto their development PC. Subsequently all modifications, build and test cycles are done on the development PC. Once changes are ready to be put back into the repository, the engineer will perform a 'cvs commit' which writes changes from the engineer's PC into the repository. The cvs commit will prompt the user for a description of the changes and these changes are stored in the repository and automatically added to the top of the source code files.	

3.12 (C)	What self-diagnostics are provided? What is the % diagnostic coverage achieved? What state does the output go in the event a fault being detected?
Regarding the Prognosis application as a whole, the integrity of the diagnostic results depend almost entirely on the integrity of the DP signals from the field. Should there be an inaccuracy in the inputs received by Prognosis whether this be an instrumentation or communications issue, Prognosis will alert the Operator to a 'DP Integrity' issue and is able in most cases to automatically identify which DP input is in error. This gives the Prognosis diagnostic system 'self-diagnostic' functionality.	

Section 3.13

3.13 (A)	How many units are in service in the field? How long have they been in use? What is the MTBF and does the field experience support this? What type of applications are the devices being used for? (Where possible the relationship of the above information to the version of software used should be provided, where not possible it should be stated that discrimination between software versions is not possible).
See also question 2 (L). Software versions are displayed clearly in the Prognosis User Interface ('Home' display). Applications for Prognosis include measurement of: Dry Gas Single Phase Liquid Wet Gas Water in Oil Heavy Oil Steam	

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SECTION 4 – Additional Requirement in the absence of ISO 9000 Part 3 Certification

General Quality Assurance

If the manufacturer does not have certification to ISO 9000 Part 3 and TICK IT for design development and manufacture of the type of instrument under consideration, then additional criteria will need to be satisfied.

1. The system should be developed in accordance with a lifecycle model which includes a clear definition of the inputs and outputs of each of the lifecycle stages and the criteria for moving from one stage to the next.
2. The following stages should be addressed: Requirements Analysis and Specification, Design, Implementation, Validation, Installation, Acceptance and Introduction to Service, Operation Maintenance, and Post-acceptance Development.
3. A plan should be prepared which identifies the task and activities necessary at each stage of the lifecycle to produce a Safety Case for the Instrument.
4. At the end of each lifecycle stage the outputs of that stage should be checked to confirm that they have been correctly derived from the inputs to that stage e.g. each process should have a corresponding verification activity.
5. Each subsystem and system should have associated with it a corresponding validation activity.
6. Verification and validation staff should be independent from the development staff.
7. For all modifications, an analysis of any verification and validation processes to be repeated should be carried out and the necessary checks performed.
8. A Quality Plan, formally reviewed and agreed by the parties should be produced at the start of the development and updated throughout the project.
9. A series of planned and documented audits should be performed to verify compliance with quality management is met.
10. The software should be verified for conformity to the chosen programming standards.

Please supply details in writing below, or attach supporting documentation, to satisfy all the above criteria.

1.	Systems are developed in accordance with the lifecycle model. Each project has a list of Milestones (lifecycle stages) and each milestone has certain criteria which must be met. The Milestones and the evidence of completion are available on the company Management Information System (MIS) where they can be checked by QA and Operations and Project Management.
2.	Requirements Analysis and Specification, Design, Implementation, Validation, Installation, Acceptance and Introduction to Service, Operation Maintenance, and Post-acceptance Development are all milestones on MIS
3.	A Safety Case for the Instrument – N/A
4.	Verification activity for each milestone is documented on MIS
5.	Verification activity for each system and subsystem is documented on MIS
6.	Dedicated Test engineers (verification staff) are used on all projects. Dedicated Inspection are used on all projects.

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7.	All modifications go through the same Design / Implement / Check cycle as the original work
8.	Quality Plans are issued at the start of all projects and updated and re-issued as required
9.	Projects are audited in accordance with the Company Audit Procedure. Individual projects are audited. Project areas may be audited as part of the audits of Core Processes. All audits are documented and corrective actions reviewed. An Audit summary is produced for each Quality Management Review Meeting. Audit Programmes are drawn up every year.
10.	Code Reviews are performed on a regular basis

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SECTION 5 – Information on the product evaluated by Evaluation International

This information is required to show if the product is likely to be commercially available for some reasonable time into the future, and to give an indication of the likely reliability in service. The statements provided should be limited to half an A4 page of typescript in total, using the headings of Section 5.1 to 5.5 as a guide.

5.1	Is the product evaluated being produced elsewhere in your organisation? If so, state where. Are all/any parts of the product fully interchangeable, regardless of origin?
N/A	

5.2	What is the expected product lifetime?
The specific software supplied for evaluation has a lifetime as long as the PC and/or Microsoft Operating System on which it is installed.	

5.3	What is the guarantee period for the hardware and software (if applicable) of the product being evaluated?
The hardware (PC) guarantee is 12 months in line with the manufacturer's warranty. The software guarantee is also 12 months, however ST can offer support contracts in order that the software is supported and/or upgrades offered for as long as it is in use.	

5.4	For how long after manufacture of the product ceases, will you provide service/maintenance facilities and spare parts?
The software product is continuously being developed and ST can offer support contracts in order that the software is supported and/or upgrades offered for as long as it is in use.	

5.5	Are installation/maintenance manuals available in both English and French? Please state their availability in any other language.
The Prognosis User Manual and Configuration Manual are currently available in English only.	

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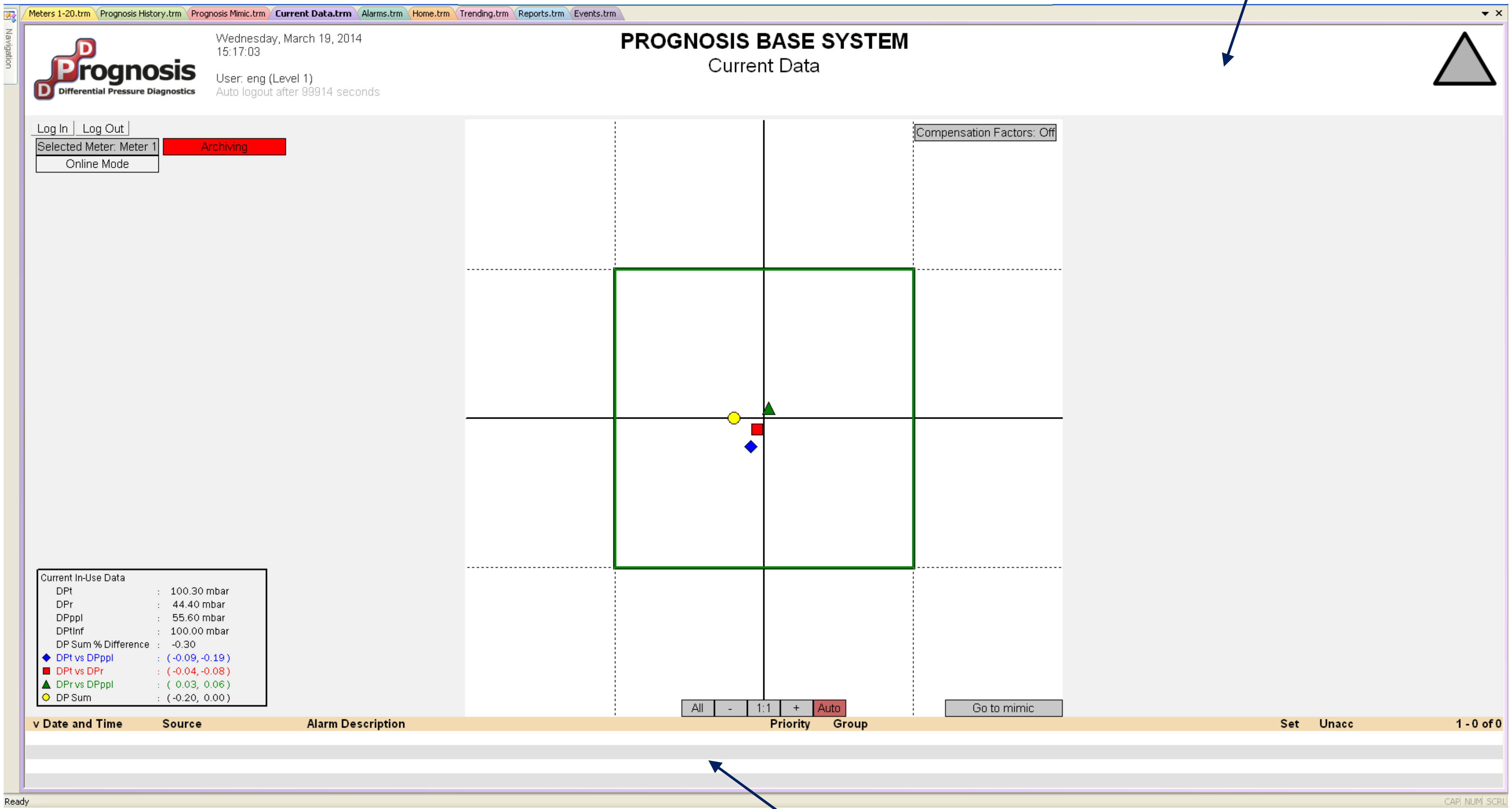
PLEASE PROVIDE YOUR COMMENTS WITHIN THE REQUIRED FOUR WEEK PERIOD

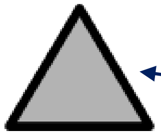
STANDARD PROGNOSIS DISPLAYS

The Prognosis User Interface has the following standard displays:

1. **Current Data** - Displays diagnostic response in real time for the selected meter

Information banner is present on every displayed (not always shown below)

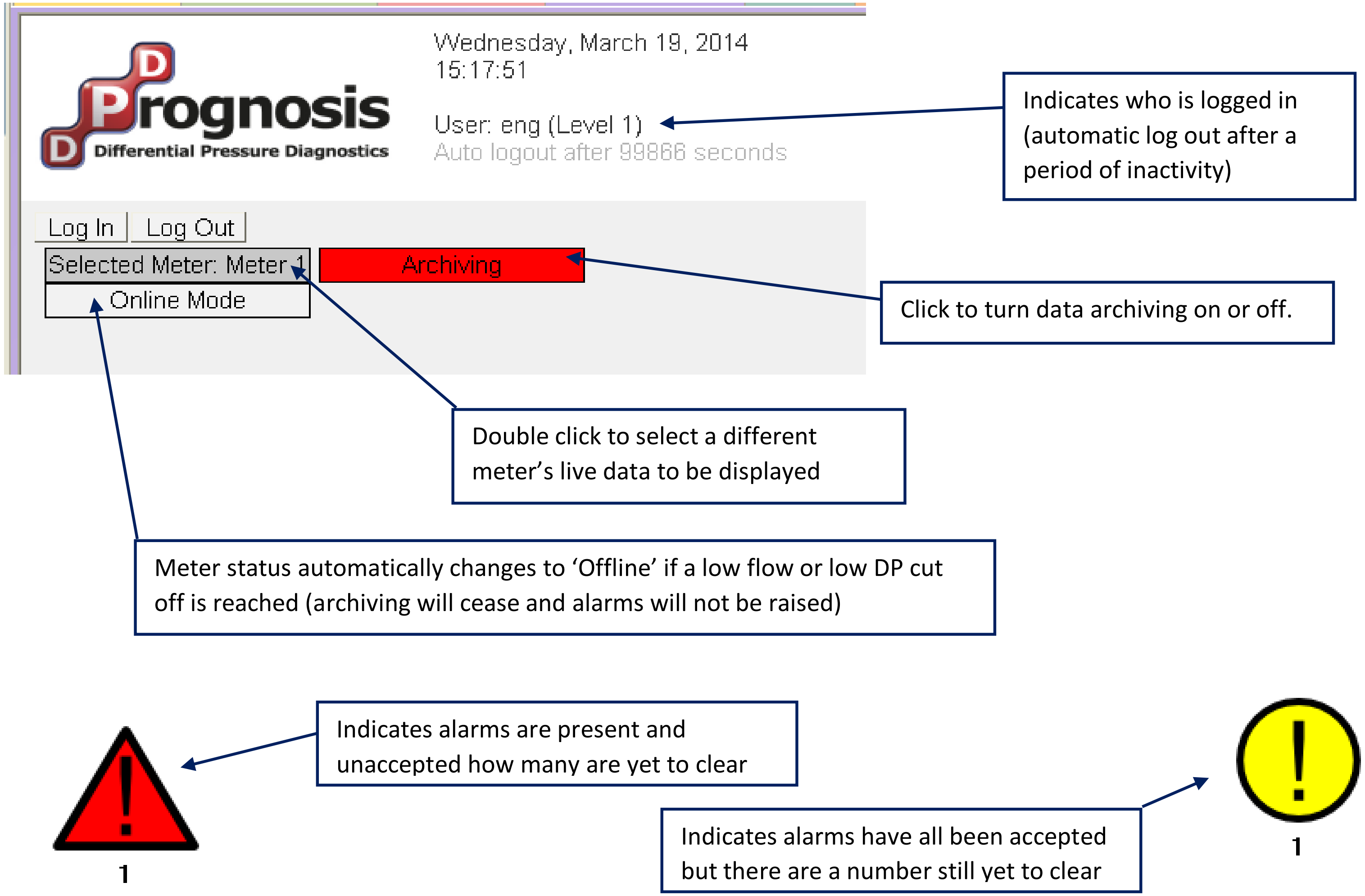




Indicates no alarms present

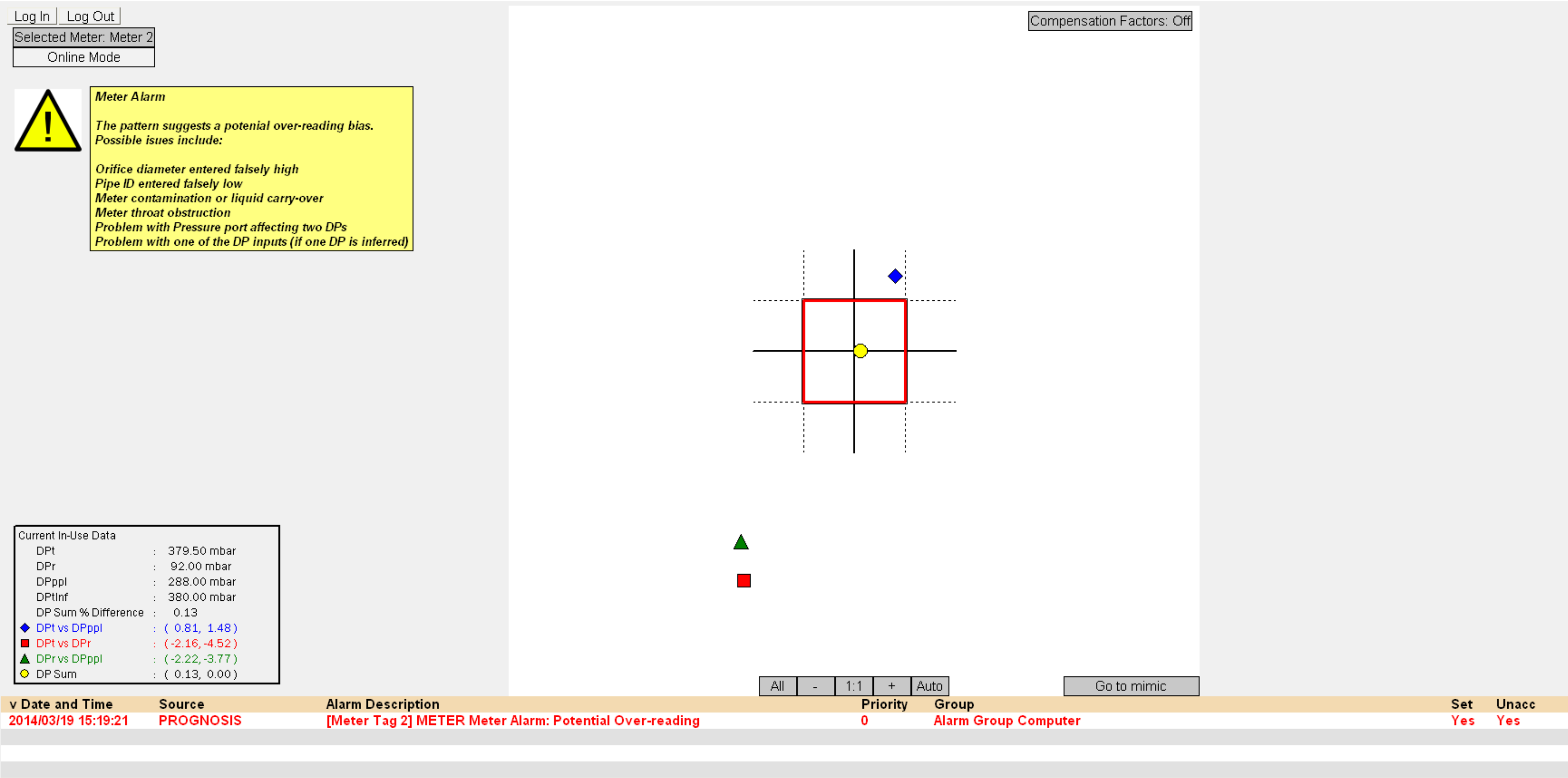
Alarm banner displays latest alarms and events raised (double click to toggle between alarms and events)

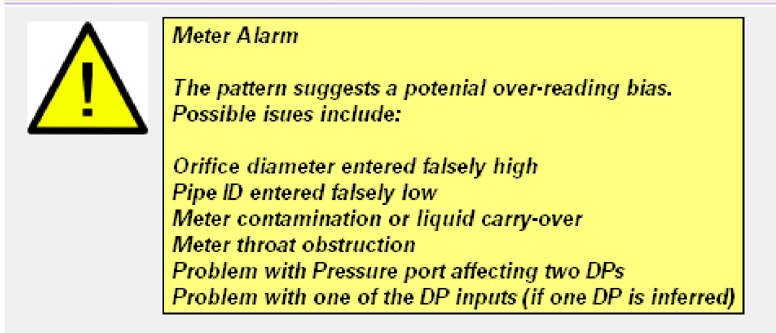
...Current Data

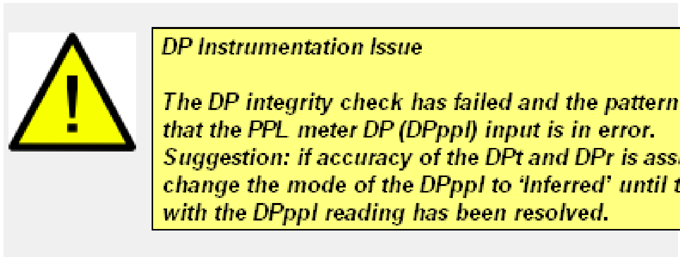


When the diagnostic response produces an alarm i.e., one or more of the SEVEN diagnostic results is outside of the NDB, the alarm has a corresponding integer value and an alarm 'message' is displayed on the main user interface providing suggestions as to the possible causes of the alarm. If the 'fourth point' (the yellow circle, which represents the DP integrity check) is outside of the NDB this tells the Operator categorically that there is an issue with one or more of the DP measurement (regardless of any other issue).

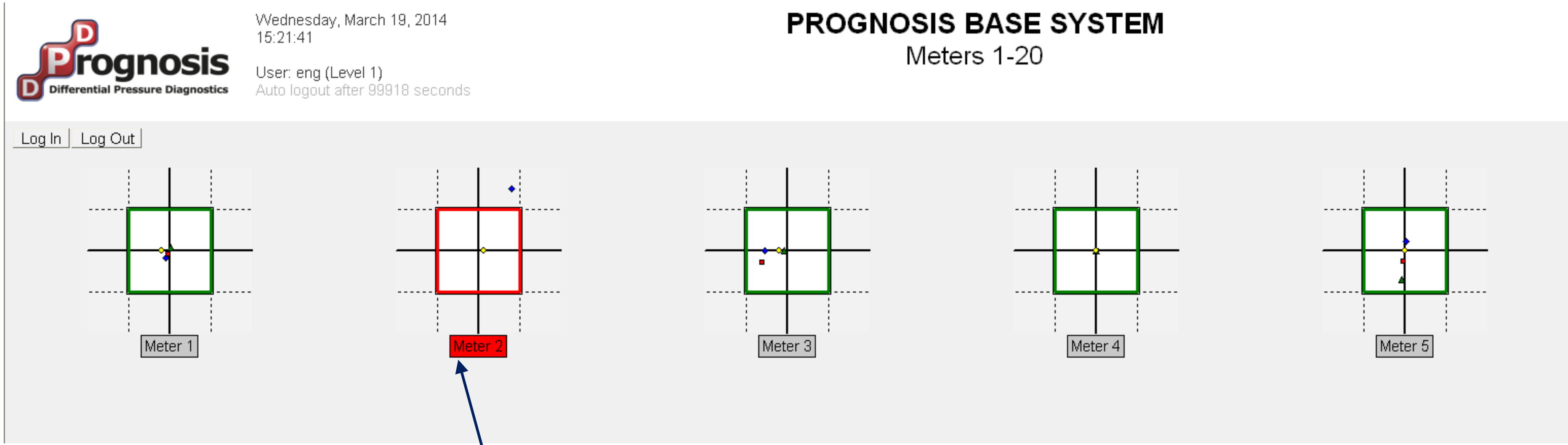
...Current Data. Examples of alarm messages below:





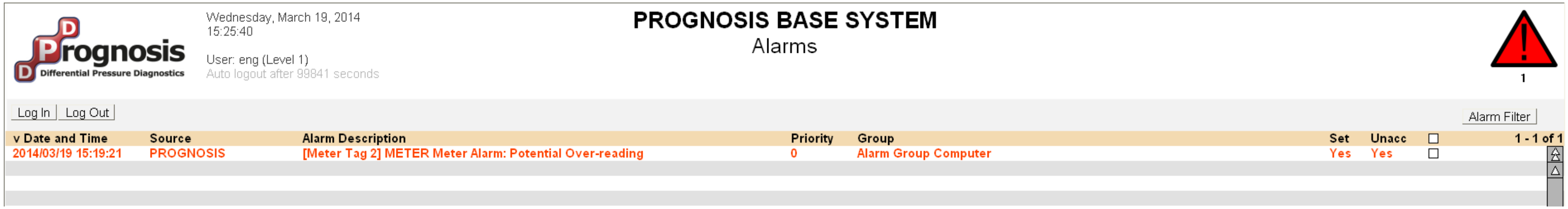


2. **<u>Meters 1-20</u> –** Displays mini real time NDBs for all of the meters being monitored by the software



Click on the meter description to jump to the 'Current Data' view for that meter

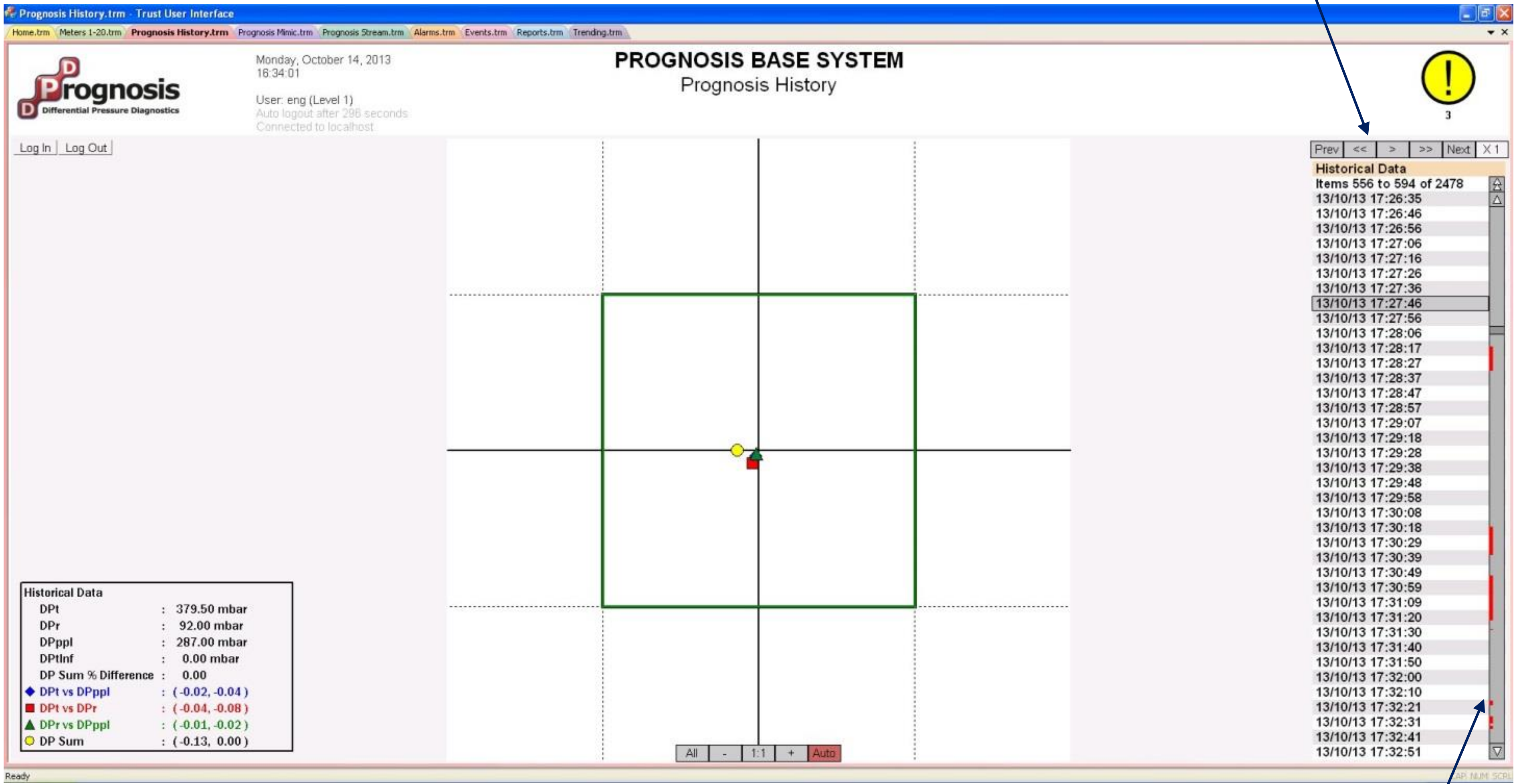
3. **<u>Alarms –</u>** Displays all alarms present in the system.



Alarms include Prognosis Alarms, Comms Links failures and upper/lower measured data alarms (if configured).
Users can filter Alarms, attach priorities and accept alarms.

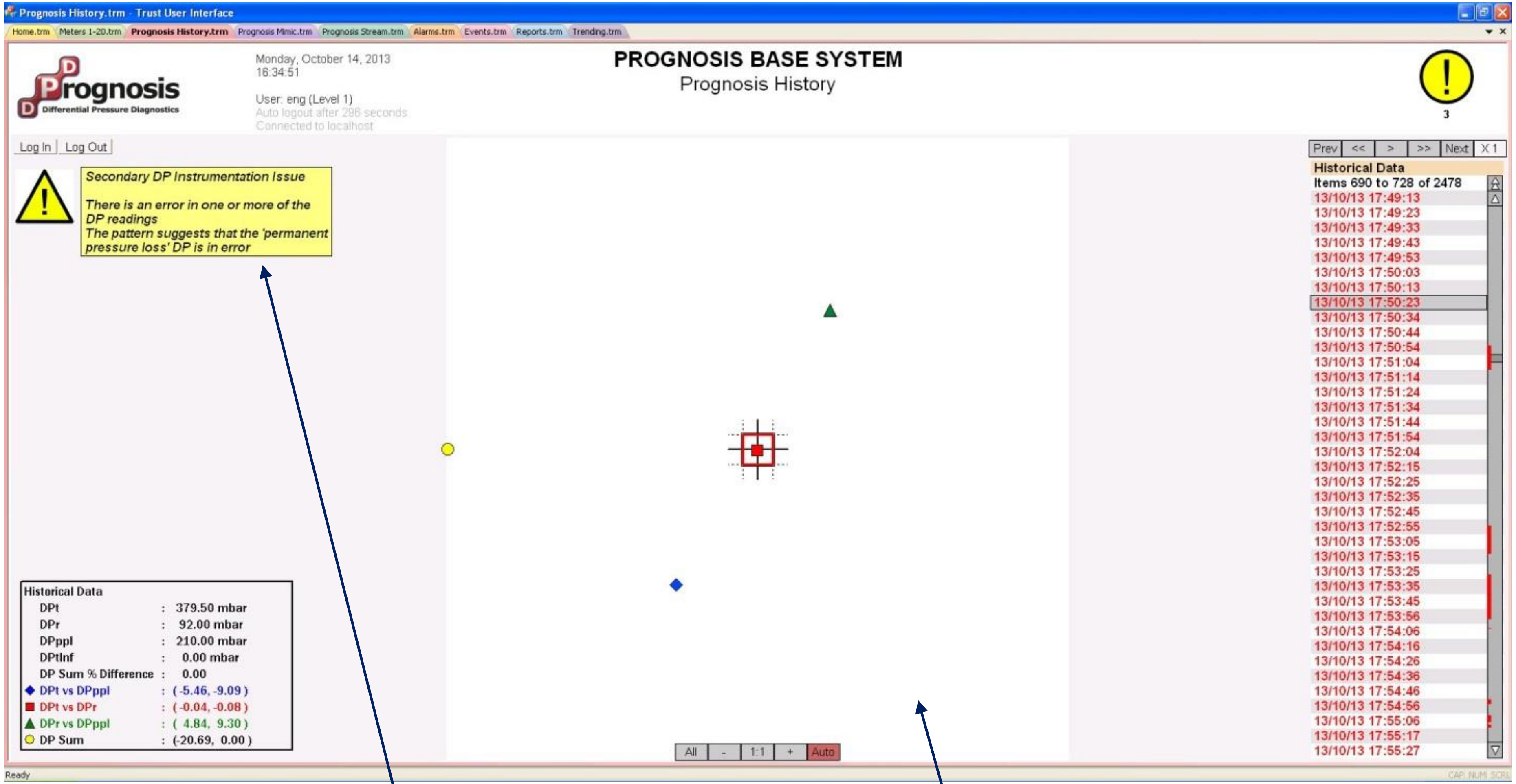
4. **Prognosis History** – Selecting this display the end user can load any previously recorded archive file for any meter and ‘playback’ in real time or at an advanced rate.

‘Playback’ controls



Red markers indicate which data was in alarm enabling the user to quickly jump to ‘problem’ data and confirm the date/time that the issue started

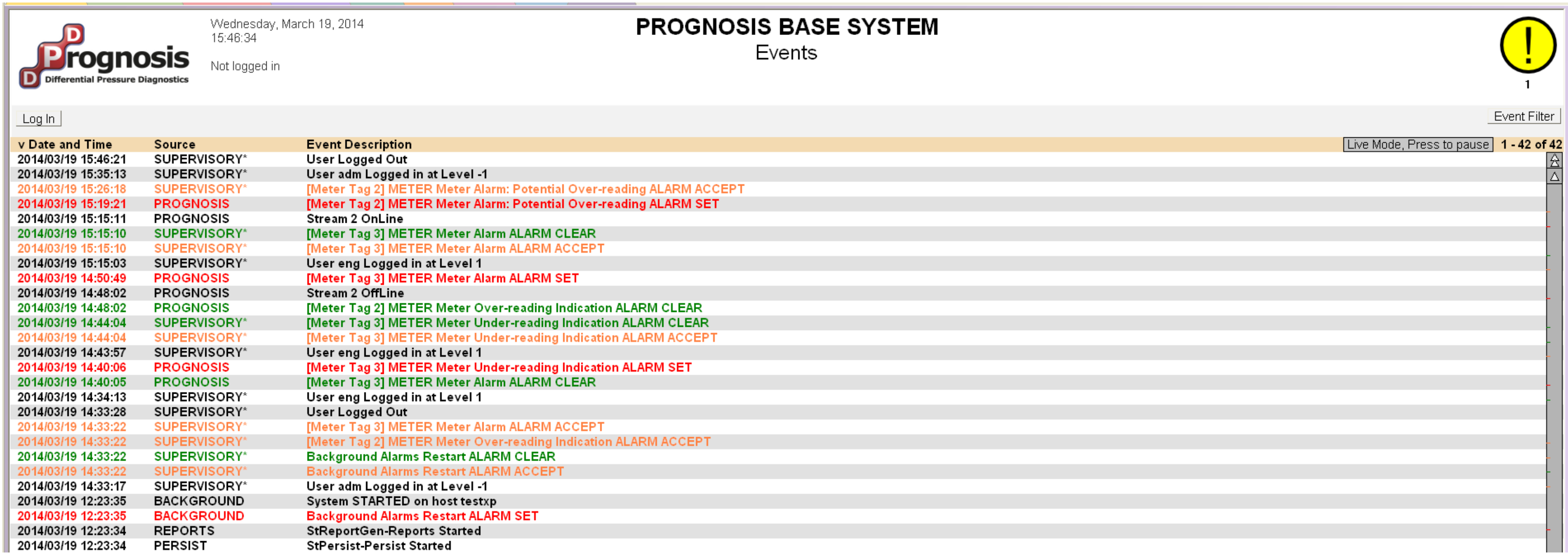
…**Prognosis History**



The alarm 'description' for each recorded data point is displayed in the Prognosis History display

All data which has been archived (inputs, outputs and intermediate values) can be viewed in a dialog for any recorded data point by double-clicking on the screen

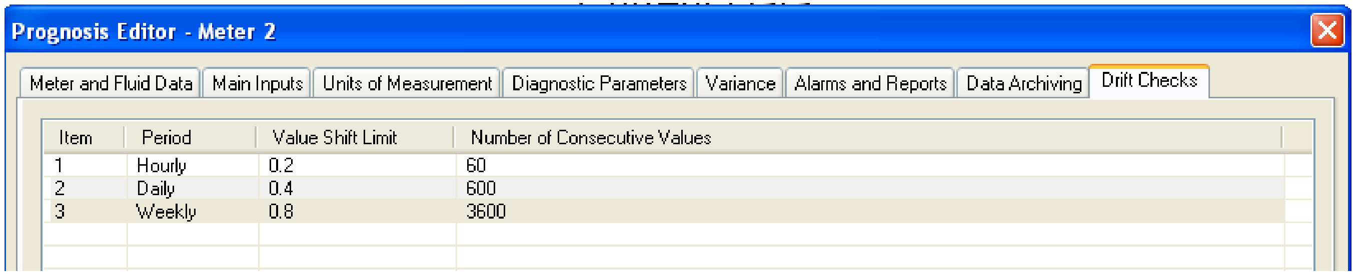
5. **Events** – Displays historical events



v Date and Time	Source	Event Description
2014/03/19 15:46:21	SUPERVISORY*	User Logged Out
2014/03/19 15:35:13	SUPERVISORY*	User adm Logged in at Level -1
2014/03/19 15:26:18	SUPERVISORY*	[Meter Tag 2] METER Meter Alarm: Potential Over-reading ALARM ACCEPT
2014/03/19 15:19:21	PROGNOSIS	[Meter Tag 2] METER Meter Alarm: Potential Over-reading ALARM SET
2014/03/19 15:15:11	PROGNOSIS	Stream 2 OnLine
2014/03/19 15:15:10	SUPERVISORY*	[Meter Tag 3] METER Meter Alarm ALARM CLEAR
2014/03/19 15:15:10	SUPERVISORY*	[Meter Tag 3] METER Meter Alarm ALARM ACCEPT
2014/03/19 15:15:03	SUPERVISORY*	User eng Logged in at Level 1
2014/03/19 14:50:49	PROGNOSIS	[Meter Tag 3] METER Meter Alarm ALARM SET
2014/03/19 14:48:02	PROGNOSIS	Stream 2 OffLine
2014/03/19 14:48:02	PROGNOSIS	[Meter Tag 2] METER Meter Over-reading Indication ALARM CLEAR
2014/03/19 14:44:04	SUPERVISORY*	[Meter Tag 3] METER Meter Under-reading Indication ALARM CLEAR
2014/03/19 14:44:04	SUPERVISORY*	[Meter Tag 3] METER Meter Under-reading Indication ALARM ACCEPT
2014/03/19 14:43:57	SUPERVISORY*	User eng Logged in at Level 1
2014/03/19 14:40:06	PROGNOSIS	[Meter Tag 3] METER Meter Under-reading Indication ALARM SET
2014/03/19 14:40:05	PROGNOSIS	[Meter Tag 3] METER Meter Alarm ALARM CLEAR
2014/03/19 14:34:13	SUPERVISORY*	User eng Logged in at Level 1
2014/03/19 14:33:28	SUPERVISORY*	User Logged Out
2014/03/19 14:33:22	SUPERVISORY*	[Meter Tag 3] METER Meter Alarm ALARM ACCEPT
2014/03/19 14:33:22	SUPERVISORY*	[Meter Tag 2] METER Meter Over-reading Indication ALARM ACCEPT
2014/03/19 14:33:22	SUPERVISORY*	Background Alarms Restart ALARM CLEAR
2014/03/19 14:33:22	SUPERVISORY*	Background Alarms Restart ALARM ACCEPT
2014/03/19 14:33:17	SUPERVISORY*	User adm Logged in at Level -1
2014/03/19 12:23:35	BACKGROUND	System STARTED on host testxp
2014/03/19 12:23:35	BACKGROUND	Background Alarms Restart ALARM SET
2014/03/19 12:23:34	REPORTS	StReportGen-Reports Started
2014/03/19 12:23:34	PERSIST	StPersist-Persist Started

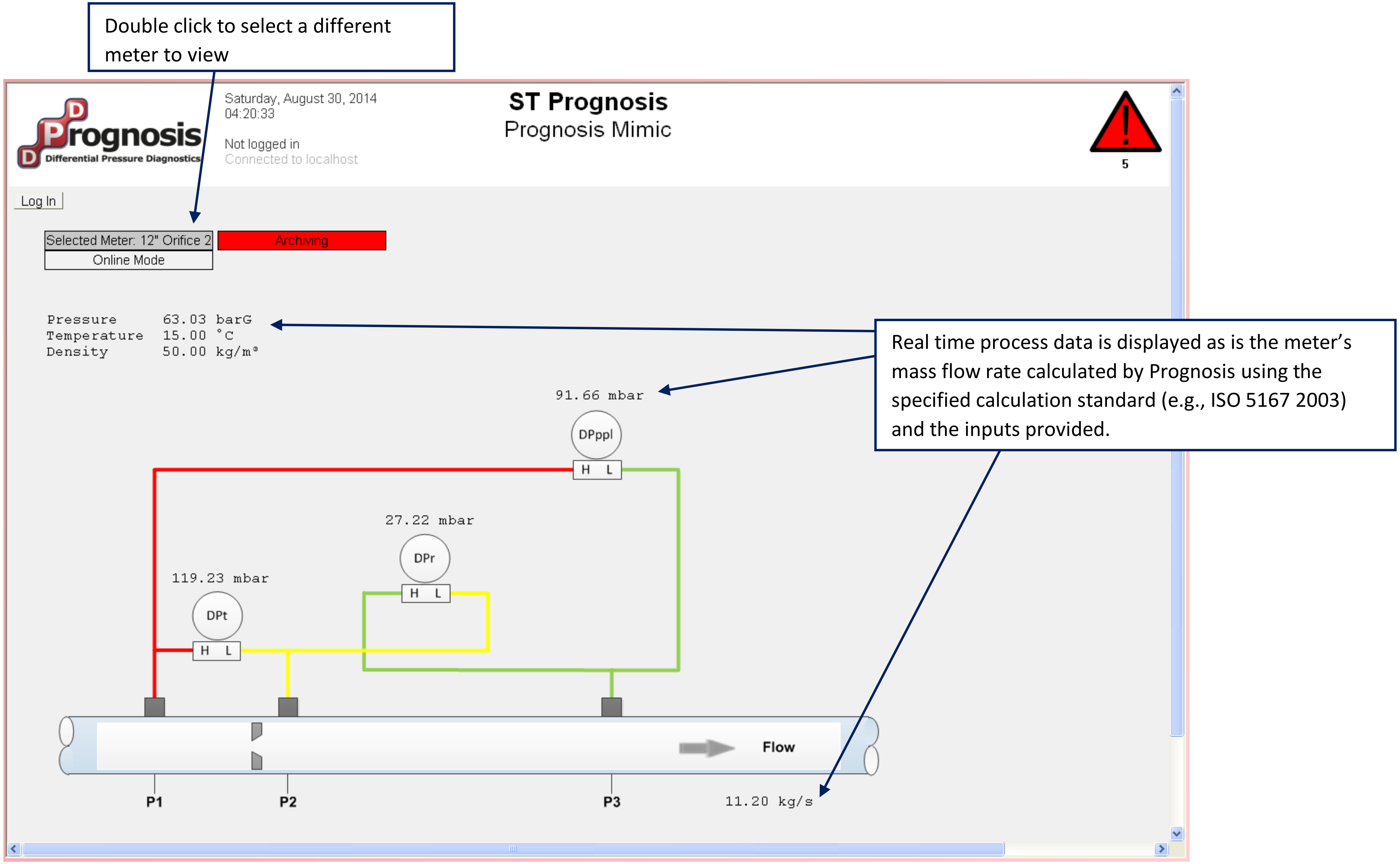
Recorded events include alarms raised, alarms cleared, users logged on, settings changed etc etc.
Events are colour-coded to indicate Alarms, settings changed and information only events.
Users can filter events by searching for keywords or categories.

In the Prognosis settings pages for each meter the user can configure '**Drift Checks**' which will cause 'events' to be logged. For example the user may configure a check which raises an event if any one of the seven diagnostic results changes by a magnitude of 0.5 over 60 consecutive seconds within the last hour etc.

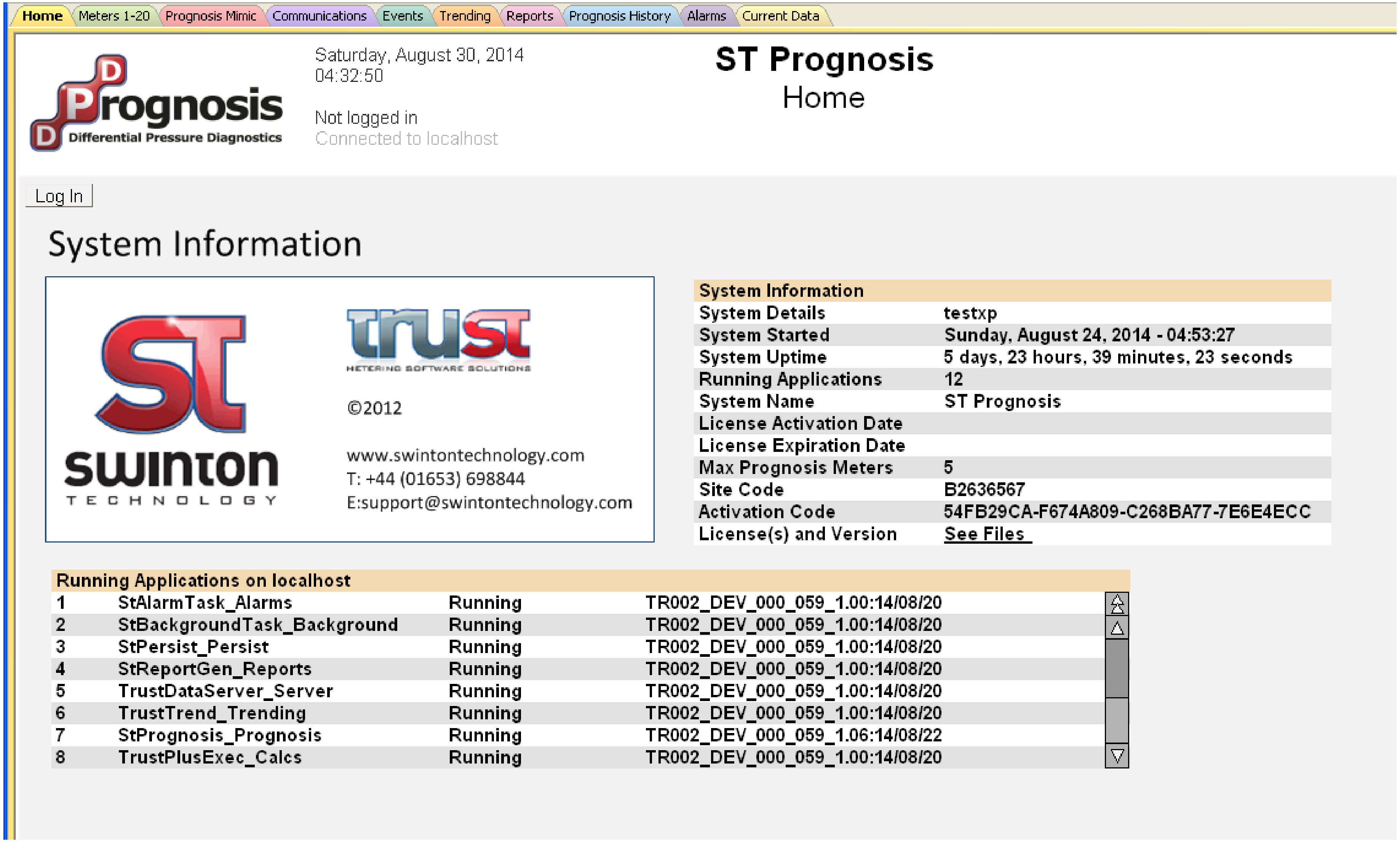


Item	Period	Value Shift Limit	Number of Consecutive Values
1	Hourly	0.2	60
2	Daily	0.4	600
3	Weekly	0.8	3600

6. **Prognosis Mimic** – A simple illustration of the selected meter (mimic changes depending on meter type)



7. **Home Page** – Displays system information, license details and software application version etc.



8. **Trending** – displays real time and historical trends for any selected meter

Standard trends sample data once every minute and display the 3 inuse DPs and the 7 diagnostic results on one trend display.

The end user can re-scale the y-axis easily to view the diagnostic results only.

…Trending

The above example shows a very ‘unsteady’ diagnostic response with all of the results moving randomly between -1 and +1, however in practice, the end user will be able to pick out trends.

Controls enable the user to zoom in and out and select a date range of trended data to view.

9. **Reports** – list of daily and/or monthly reports automatically generated by Prognosis

Meters 1-20 | Prognosis History | Prognosis Mimic | Current Data | communications | home | trending | Alarms | Events | Reports

Prognosis
Differential Pressure Diagnostics

Thursday, April 10, 2014
00:01:23

Not logged in
Connected to localhost

PROGNOSIS BASE SYSTEM

Reports

Log In

v Date and Time	Source	Report Name	Report Path
2014/04/07 00:00:09	PROGNOSIS	Meter 1 Daily	c:/TRUST/reports/2014/04/07/PROGNOSIS/MTR_1_DAILY/MTR_1_DAILY_2014_04_07_00_00_00.pdf
2014/04/06 00:00:09	PROGNOSIS	Meter 1 Daily	c:/TRUST/reports/2014/04/06/PROGNOSIS/MTR_1_DAILY/MTR_1_DAILY_2014_04_06_00_00_00.pdf
2014/04/05 00:00:09	PROGNOSIS	Meter 1 Daily	c:/TRUST/reports/2014/04/05/PROGNOSIS/MTR_1_DAILY/MTR_1_DAILY_2014_04_05_00_00_00.pdf

Select and double-click to open a report in .pdf format.

```
                              Summary

           Site Name                  : Site 1
           Asset Name                 : Asset 2
           Meter Tag                  : Meter Tag 1
           Report Status              : 1.52% IN ALARM
           Number of results averaged : 987
           Alarm Delay Setting        : 60

-----------------------------------------------------------------------------

                              Statistics

                    % of period Diagnostics alarm raised
                    ------------------------------------
  1. Meter Over-reading Indication                     (%)    :    0.51
  2. Meter Under-reading Indication                    (%)    :    0.00
  3. Meter Alarm: Potential Over-reading               (%)    :    1.01
  4. Meter Alarm: Potential Under-reading              (%)    :    0.00
  5. DP Measurement Issue                              (%)    :    0.00
  6. DP Measurement Issue: Possible DPt (P1-P2) Error  (%)    :    0.00
  7. DP Measurement Issue: Possible DPr (P3-P2) Error  (%)    :    0.00
  8. DP Measurement Issue: Possible DPppl (P1-P3) Error(%)    :    0.00
  9. Meter Alarm: Potential Geometry Error             (%)    :    0.00
  10.Meter Alarm: Potential Discharge Coefficient Error(%)    :    0.00
  11.Meter Alarm                                       (%)    :    0.00

                        Longest Time Alarm Raised
                        -------------------------
  1. Meter Over-reading Indication                     (secs) :    3.00
  2. Meter Under-reading Indication                    (secs) :    0.00
  3. Meter Alarm: Potential Over-reading               (secs) :    5.00
  4. Meter Alarm: Potential Under-reading              (secs) :    0.00
  5. DP Measurement Issue                              (secs) :    0.00
  6. DP Measurement Issue: Possible DPt (P1-P2) Error  (secs) :    0.00
  7. DP Measurement Issue: Possible DPr (P3-P2) Error  (secs) :    0.00
  8. DP Measurement Issue: Possible DPppl (P1-P3) Error(secs) :    0.00
  9. Meter Alarm: Potential Geometry Error             (secs) :    0.00
  10.Meter Alarm: Potential Discharge Coefficient Error(secs) :    0.00
  11.Meter Alarm                                       (secs) :    0.00

                             Average Values
                             --------------
  DPt                                                  (mbar) :  500.00
  DPr                                                  (mbar) :  200.00
  DPppl                                                (mbar) :  300.50
  DP Sum % Difference                                  (%)    :  0.10
  Pressure                                             (barA) :  52.00
  Flowrate                                             (kg/s) :  11.09

                  Average Normalised Diagnostic Results
                  -------------------------------------
  X1 - Flowrate inter-comparison, DPt v DPppl                 : 0.2131
  X2 - Flowrate inter-comparison, DPt v DPr                   : -0.0416
  X3 - Flowrate inter-comparison, DPppl v DPr                 : -0.5029
  Y1 - DP Ratio comparison actual v expected, DPppl/DPt       : 0.5210
  Y2 - DP Ratio comparison actual v expected, DPr/DPt         : -0.1177
  Y3 - DP Ratio comparison actual v expected, DPr/DPppl       : -0.3628
  X4 - DPt actual v DPt inferred                              : 0.3000
```

An example report is shown left and indicates the following:

1.52% of the 987 results considered (i.e., 15 results) raised a Prognosis alarm.

Alarm result 1 was raised 0.51% of the time (this equates to 5 seconds in total), however the longest consecutive time the alarm was raised was 3 seconds.

Alarm result 3 was raised 1.01% of the time (this equates to 10 seconds in total), however the longest consecutive time the alarm was raised was 5 seconds.

So, even after an 'alarm delay' of 60 seconds an alarm still triggered BUT it was never sustained for longer than 5 seconds.

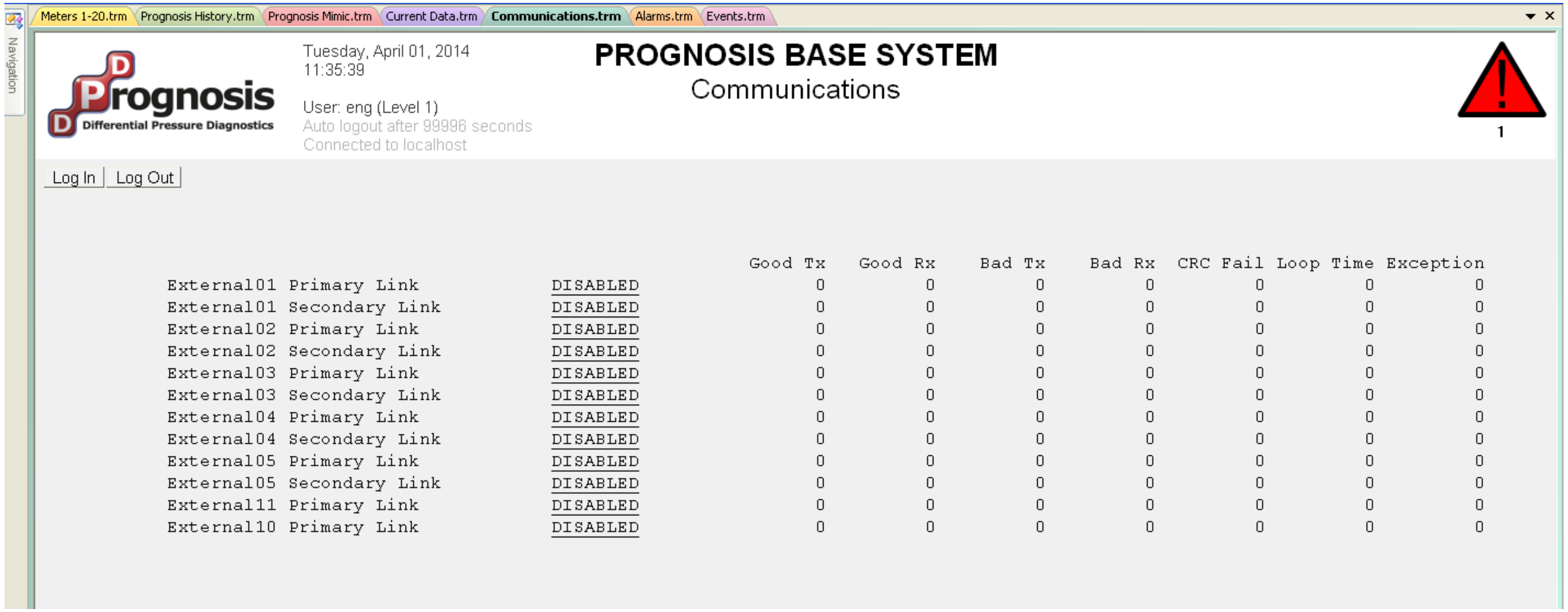
The report statistics will give the user a summary pf the meter performance and help to identify (if appropriate) an optimal 'alarm delay' setting in order to avoid 'false alarms' caused by natural variances in process conditions.

The average values can help to identify 'trends' in meter performance and the average diagnostic results can be used as evidence of the meter performance over time

10. **<u>Communications</u>** – list of daily and/or monthly reports automatically generated by Prognosis

Any configured Modbus communications links (either for data acquisition or data hand off) are listed and can be monitored from this display.

Slave links set up via the ‘External Communications’ dialog will be listed here; ‘Primary Link’ corresponds to ‘Comms Setting A’ and ‘Secondary Link’ corresponds to ‘Comms Settings B’ and the link will only appear if the corresponding comms settings have been entered.



		Good Tx	Good Rx	Bad Tx	Bad Rx	CRC Fail	Loop Time	Exception
External01 Primary Link	DISABLED	0	0	0	0	0	0	0
External01 Secondary Link	DISABLED	0	0	0	0	0	0	0
External02 Primary Link	DISABLED	0	0	0	0	0	0	0
External02 Secondary Link	DISABLED	0	0	0	0	0	0	0
External03 Primary Link	DISABLED	0	0	0	0	0	0	0
External03 Secondary Link	DISABLED	0	0	0	0	0	0	0
External04 Primary Link	DISABLED	0	0	0	0	0	0	0
External04 Secondary Link	DISABLED	0	0	0	0	0	0	0
External05 Primary Link	DISABLED	0	0	0	0	0	0	0
External05 Secondary Link	DISABLED	0	0	0	0	0	0	0
External11 Primary Link	DISABLED	0	0	0	0	0	0	0
External10 Primary Link	DISABLED	0	0	0	0	0	0	0

If a link is disabled then no corresponding alarms will be raised (they will be inhibited) although a ‘Link Disabled’ alarm will be set until the link is enabled again. If a link’s status is enabled then possible alarms are:

- Bad Tx
- Bad Rx

If a data hand off link has been configured it will also be listed in this display also (with no ‘ENABLE/DISABLED’ button) for diagnostic purposes.