DP Meter Verification System – End User Experience

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ABSTRACT

The DP meter verification system 'Prognosis' has been growing in popularity as a means of verifying DP meter performance and reducing maintenance costs. Repeatedly proven with successful laboratory tests and field trials in the UK, USA, Russia, Mexico, Malaysia, Middle East, and India it is now established with multiple systems in industrial use. This system's methodology is referenced in various regulator documents (e.g. UK and Canadian regulators), by ISO TR 12748, and in producer internal handbooks.

Field data from multiple sources will be presented focusing on the advantages to the end user of using this system for assurance of good meter performance and alerting the user to any potential meter system issues. This data shows real world DP meter performances with their self-diagnostic capabilities fully utilised. It shows that the verification system is practical and relatively easy to learn and use. It also shows how the diagnostic information can be used for optimal end user benefit.

Increasing use throughout industry has led to multiple field examples from different sources showing the practical usefulness of the system for verifying the serviceability of DP meters.

For further details the reader should refer to the descriptions given by Steven [1, 2], Skelton et al [3] & Rabone et al [4].

KEY WORDS

Differential Pressure Meters, Verification, Diagnostics, Gas and Liquid Metering, Orifice.

INTRODUCTION

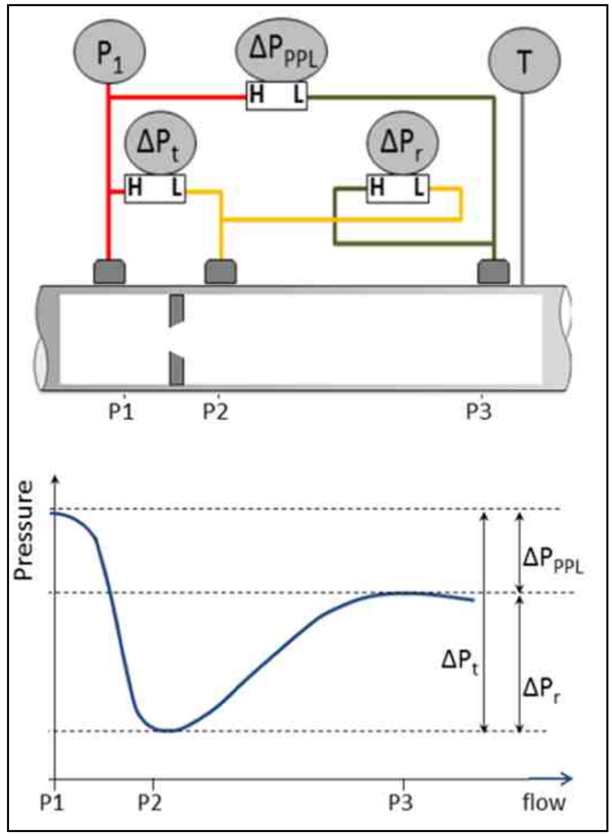

Figure 1 - Orifice meter with instrumentation sketch and pressure field graph

Figure 1 shows a sketch of a generic DP meter with three DP readings and a simplified pressure field created by the meter. The DP meter has a third pressure tap (P3) downstream of the two traditional pressure ports which is ideally, but not critically 6D[1] downstream of the meter body. This allows three DPs to be read, i.e. the traditional (ΔP_t), recovered (ΔP_r) and permanent pressure loss (ΔP_{PPL}) DPs. These DPs are related by equation 1. The

[1] For details, the reader should refer to Skelton [3]

percentage difference between the inferred traditional DP (i.e. the sum of the recovered & PPL DPs) and the read DP is δ%, while the maximum allowed difference is θ%.

DP Summation (uncertainty ± θ%):

$$\Delta P_t = \Delta P_r + \Delta P_{PPL} \quad \text{--- (1)}$$

Each DP can be used to meter the flow rate, as shown in equations 2, 3 & 4. Here $\dot{m}_{trad}$, $\dot{m}_{\exp}$ & $\dot{m}_{PPL}$ are the mass flow rate predictions of the traditional, expansion & PPL flow rate calculations.

Traditional flow calculation (uncertainty ± x%):

$$\dot{m}_{trad} = f_t(\Delta P_t) \quad \text{--- (2)}$$

Expansion flow calculation (uncertainty ± y%):

$$\dot{m}_{\exp} = f_r(\Delta P_r) \quad \text{--- (3)}$$

PPL flow calculation (uncertainty ± z%):

$$\dot{m}_{PPL} = f_{PPL}(\Delta P_{PPL}) \quad \text{--- (4)}$$

Every DP meter is three flow meters in one body. Symbols f_t, f_r & f_{PPL} represent the traditional, expansion & PPL flow rate calculations respectively, and, $x\%$, $y\%$ & $z\%$ represent the uncertainties of each of these flow rate predictions respectively. Inter-comparison of these flow rate predictions produces three diagnostic checks. The percentage difference of the PPL to traditional flow rate calculations is denoted as $\psi\%$. The allowable difference is the root sum square of the PPL & traditional meter uncertainties, $\phi\%$. The percentage difference of the expansion to traditional flow rate calculations is denoted as $\lambda\%$. The allowable difference is the root sum square of the expansion & traditional meter uncertainties, $\xi\%$. The percentage difference of the expansion to PPL flow rate calculations is denoted as $\chi\%$. The allowable difference is the root mean square of the expansion & PPL meter uncertainties, $\nu\%$.

Reading these three DPs produces three DP ratios, the 'PLR' (i.e. the PPL to traditional DP ratio), the PRR (i.e. the recovered to traditional DP ratio), the RPR (i.e. the recovered to PPL DP ratio). DP meters have predictable DP ratios. Therefore, comparison of each read to expected DP ratio produces three diagnostic checks. The percentage difference of the read to expected PLR is denoted as $\alpha\%$. The allowable difference is the expected PLR uncertainty, $a\%$. The percentage difference of the read to expected PRR is denoted as $\gamma\%$. The allowable difference is the expected RPR uncertainty, $b\%$. The percentage difference of the read to expected RPR is denoted as $\eta\%$. The allowable difference is the expected RPR uncertainty, $c\%$. These seven diagnostic results can be shown on the operator interface as plots on a graph (see Figure 2). That is, we can plot the following four co-ordinates to represent the seven diagnostic checks: $(\psi\%/\phi\%, \alpha\%/a\%)$, $(\lambda\%/\xi\%, \gamma\%/b\%)$, $(\chi\%/\nu\%, \eta\%/c\%)$ and $(\delta\%/\theta\%, 0)$.

For simplicity we can refer to these points as (x_1,y_1), (x_2,y_2), (x_3,y_3) & $(x_4,0)$.

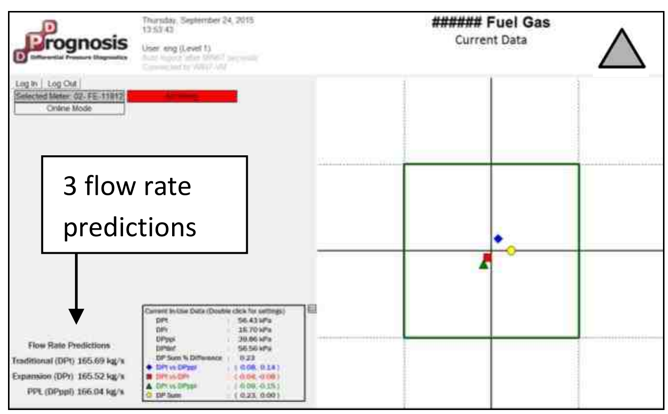

Figure 2 - Display showing NDB and diagnostic results (good meter performance)

Dividing the seven raw diagnostic outputs by their respective uncertainties is called 'normalization'. A Normalized Diagnostics Box (or 'NDB') of corner coordinates (1, 1), (1,-1), (-1,-1) & (-1, 1) can be plotted on the same graph (see Figure 2). This is the standard user interface with the diagnostic system ‘Prognosis’. All four diagnostic points inside the NDB indicate a serviceable DP meter. Any point outside of the NDB indicates a possible meter system malfunction and potential measurement bias.

By analyzing the diagnostic response continually and in real time (with no Operator intervention required), the Prognosis software will automatically provide a system alarm when any point is outside of the NDB for longer than a configurable ‘alarm delay’ period and also a ‘shortlist’ of possible issues which are known to cause the observed response (discounting other problems that do not cause such a response). In some cases (e.g., DP instrumentation issue), the software is able to tell the end user specifically what issue exists. In the case of an issue with the ‘traditional’ meter DP reading the diagnostic system’s flow rate prediction over-determination provides **two alternative flow rate predictions**.

EXAMPLE 1: 2 x 4” ORIFICE (0.5 BETA), OFFSHORE NORTH SEA

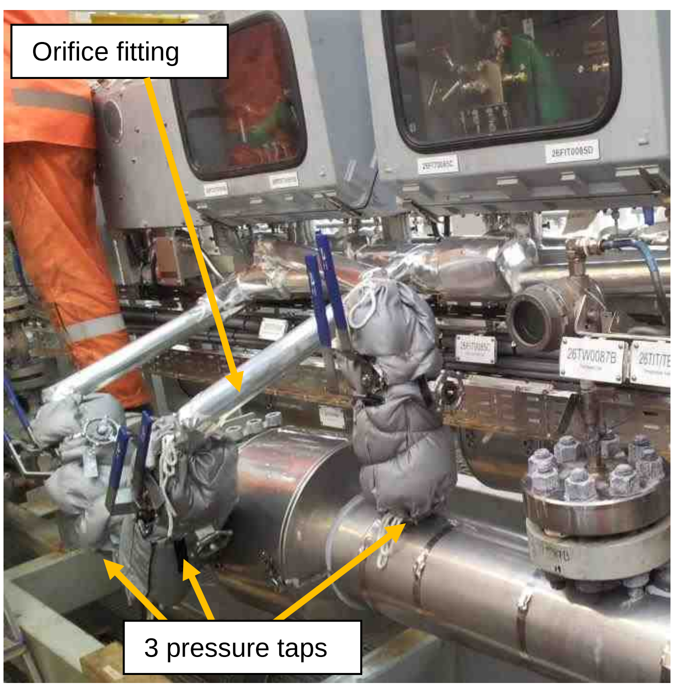

Figure 3 – Photograph of 4” orifice meter run with instrumetation

The ‘Prognosis’ DP Meter validation system was installed on two 4” orifice meters located on an FPSO in the central North Sea in early 2014. These meters measure gas which has been through two stages of separation and is the export gas to a major UK gas pipeline. Both meters have the downstream tapping point (P3) at slightly further than 6D downstream of the plate; 7.25D for Meter 1 and 7.31D for Meter 2. The corresponding standard theoretical adjustment to the expected baseline, as prompted by the validation system, was applied (as described by Skelton [3]).

Figure 3 is a photograph of one of the meter runs showing its downstream tap location. Figure 4 shows a sample Prognosis response (recorded December 2016) from one of these 4”, 0.5β orifice meters. This is a screenshot from Prognosis playing historical data recorded live on an in-service meter. All points are in the box indicating that the meter is verified to be fully serviceable. This is the typical result for Prognosis on a DP flow meter.

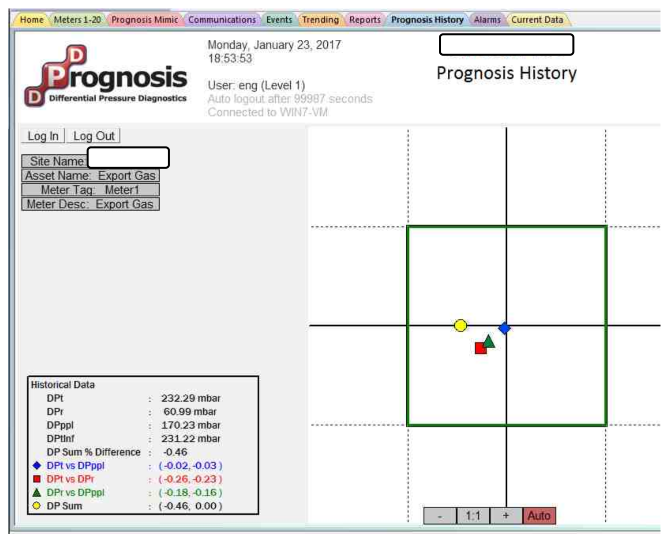

Figure 4- Example Prognosis response indicating good meter performance

Live flow meters inevitably encounter periodic flow fluctuations. Such transient flow affects could naturally cause Prognosis to momentarily register a possible event. However, such issues are easily dealt with in practice by applying suitable sensitivity, 'low flow cut off', and 'alarm delay' settings. Figure 4 has the 'averaging' sensitivity setting applied and the Operator observed this to be a stable response over time. If the validation system raises an alarm it is because there is a real problem (as will be seen in subsequent examples).

These results assure the end user that the orifice meter is fully serviceable and does not require maintenance. The Operator of these meters has successfully used Prognosis data as part of a justification for reducing maintenance and inspection frequencies relating to both the orifice plates and the DP transmitters as detailed in Table 1. This is a reduction in the associated maintenance activities of 57% overall. The corresponding estimated financial savings is £28,000 per year, every year.

Table 1– Reduction in Maintenance Activities

Device	Test	Previous Frequency	New Frequency
DP Tx	Zero check	Monthly	3 Monthly
DP Tx	Offshore verification	3 Monthly	6 Monthly
DP Tx	Onshore Footprint calibration	6 Monthly	3 Yearly
Orifice Plate	Inspection	3 Monthly	6 Monthly

EXAMPLE 2: 2 x 16" ORIFICE, ONSHORE UK NATIONAL GRID

The 'Prognosis' DP Meter validation system was applied to 2 x 16" orifice plates (0.475β) at a UK National Grid offtake. On both meter runs, the downstream tap was located slightly further upstream than the ideal location of 6D downstream of the plate. As the Prognosis downstream pressure tap location correction tool is applicable to > 6D, the standard procedure in such cases is to ascertain a baseline by utilizing the Prognosis zeroing option during system commissioning. This is analogous with ultrasonic meter diagnostic system standard practice of taking a footprint of the diagnostic suite response on initial start-up for use as a baseline. Appropriate 'Z Factors' Z = 0.008 for meter 1 and Z = 0.015 for meter 2 were applied[2].

Figure 5 shows historical data from Meter 1 from 16th March 2014. Meter 2 results were similar. No alarms are present indicating that the meters are serviceable and no maintenance is required.

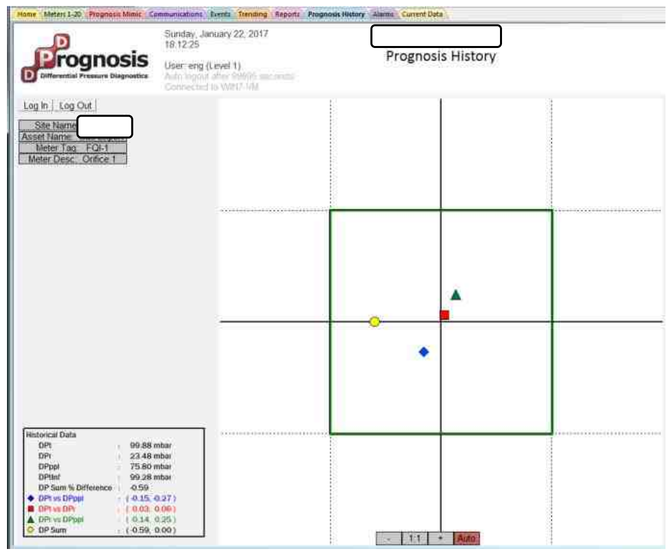

Figure 5 – Example National Grid orifice meter 'Prognosis' response (Meter 1)

The UK National Grid (like other meter users) has different flow metering uncertainty budgets for different flow rate ranges. Therefore, National Grid chose to utilize the system's option to select different diagnostic sensitivities at different flow rates. For example, a very low flow rate produces low DPs with associated higher DP reading uncertainty. Reducing the diagnostic sensitivity at low flows is another example of how industry should have no concern about false alarms.

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2 For details of how the 'Z Factor' is defined and used the reader should refer to descriptions given by Skelton [3] and Ayre [5].

EXAMPLE 3: 6" ORIFICE (0.5 BETA), SOUTH AMERICA AUDIT #1

Figure 6 – 6" Orifice Meter run prior to audit #1

A US audit company was due to audit a 6", 0.5β flanged tapped orifice meter in South America. The client had no particular concerns about the meter and the audit was only part of the routine maintenance schedule. The natural gas flow meter was operating at 858 psia/59 bara at 95^0 F. The flow rate was approximately 490 MSCFD (2.8 kg/s). The auditors installed a calmp-on USM as part of their normal audit procedure. In addition, they temporarily installed Prognosis on the meter run as part of independent assessment of the system. Figure 6 shows the meter run prior to the installation of Prognosis (and a clamp-on USM). Note that the downstream spool already had a suitable downstream pressure tap. This is a common trait amongst existing orifice meter runs.

Figure 7 shows a screenshot from Prognosis running on the meter. The DP reading diagnostic check indicates that the DPs are being read correctly, with a 0.711% difference being noted between the inferred traditional DP of 30.355 "WC and the read traditional DP of 30.141 "WC. This is lower than the nominal 1% DP reading warning threshold. The three diagnostic points are well inside the diagnostic box, and scattered around the origin. Prognosis was applying internal diagnostics to this orifice meter to show that the meter was fully serviceable, measuring the correct flow rate and did not need any maintenance.

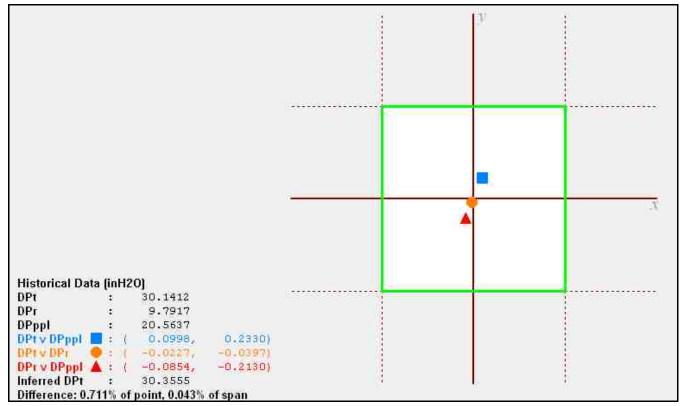


Figure 7 – Example Prognosis result observed

Due to contractual obligations and the fact that Prognosis was seen as 'on trial' the auditors continued with the audit procedure. A clamp on USM was installed to allow comparison between the orifice meter and USM flow rate predictions. The over-all uncertainty of a correctly operating orifice meter system is considered to be between 0.7% and 1%. The uncertainty stated for a clamp-on USM is 3%. Therefore, when comparing the two meters the difference between them should not be more than the root mean square of these uncertainties, i.e. approximately 3%. The actual difference was < 3%. This gave confidence that the orifice meter was operating correctly. However, it does **not** guarantee that the orifice meter has no issues.

The comparison of a clamp-on USM with an orifice meter is not sensitive enough to guarantee that the orifice meter does not have a problem. For example, say the clamp-on USM produces a flow rate prediction that is +1.5% from the actual flow rate. With a rated uncertainty of 3% this is a reasonable example. Now let us say that the orifice meter has a problem and produces a flow rate prediction that is +4% from the actual flow rate. Comparing the two flow rate outputs we would see that the difference between the two flow rate predictions is +2.5%. However, the comparison allows 3% difference before deciding something is wrong. Therefore, in this case no problem would be noticed. Hence, comparing the clamp on USM and orifice meter alone cannot guarantee the orifice meter is operating correctly.

Continuing with the contractual audit obligations, the auditors took the meter off-line (i.e. interrupted operations) to remove the orifice plate for inspection and to borescope the meter run and flow conditioner. Figure 8 shows a photograph of the plate. The plate was confirmed to have the correct orifice diameter, was found to be clean and with a sharp orifice edge.

Figure 8 – Plate inspected during audit #1

The pressure taps, orifice carrier and the flow conditioner were also boroscoped. The orifice meter system was seen to be uncontaminated with no blockage of the pressure ports or flow conditioner holes. No problem with the orifice carrier was noted. The DP transmitter was correctly sized and in calibration with no drift. Therefore, after comparing the orifice meter to a clamp-on USM, then checking the integrity of the DP transmitter and then removing the plate, checking the plate and borescoping the meter system, it was finally concluded that the orifice meter was fully serviceable just as Prognosis had initially said and the audit was then complete.

In this audit, Prognosis stated immediately that the DPs were being measured correctly and that the meter was operating correctly according to ISO 5167 and AGA 3. That is, the initial use of Prognosis showed the meter to be operating correctly. The comparison of the orifice meter to the clamp-on USM gave a less reliable assurance that the meter was operating correctly. The follow on, time consuming and costly procedure of taking the meter off line, removing the plate and inspecting it, then borescoping the meter run and checking the DP transmitter did nothing more than confirm the initial Prognosis result that the meter was fully serviceable. If meter operators were to trust Prognosis the rest of the needless time consuming costly procedure could be avoided.

Without Prognosis, if any future maintenance service finds any problem the operator may not be able to tell when the malfunction occurred. All that would be known is that there was a malfunction sometime between the two scheduled maintenance events. If Prognosis was permanently installed, if a malfunction was to occur the operators could examine archived results to pin-point when the malfunction occurred and therefore better address the mis-measurement issue.

Finally note that the alternative live diagnostic of putting a second check meter in series with the orifice meter is a lower quality diagnostic methodology. First, it is a high capital expense to add a second metering system. Once two meters are in series, they can only indicate an error if the root mean square of the two meter uncertainties is exceeded (which is not a particularly sensitive diagnostic method). Also, there is no guarantee that the meters will not suffer some common mode error thereby making their flow rate predictions equally incorrect with the inter-comparison diagnostic showing no error. (This is in contrast to the multiple diagnostic methods within Prognosis which are very resistant to most common mode error issues). Furthermore, even if the second/check meter does show a different flow rate to the primary meter this does not tell you which meter has malfunctioned. Prognosis will state if the DP meter it is monitoring has malfunctioned and what possible malfunctions could cause the diagnostic result. Hence Prognosis is advisable for permanent installation on financially important DP meters and is substantially better than the alternative method of using a second check meter.

EXAMPLE 4: 6" ORIFICE (0.35 BETA), SOUTH AMERICA AUDIT #2

Figure 9 - 6" Orifice Meter run prior to audit #2

A 6", 0.35β flanged tapped orifice meter was audited by the same US audit company as in Example 3. The natural gas flow meter was operating at 1356 psia/93.5 bara at 73^0 F. The flow rate was approximately 220 MSCFD (1.68kg/s). Prognosis and a clamp-on USM were installed. Figure 9 shows the meter run prior to the installation of Prognosis and the clamp-on USM. Figure 10 shows a screenshot from Prognosis running on this meter.

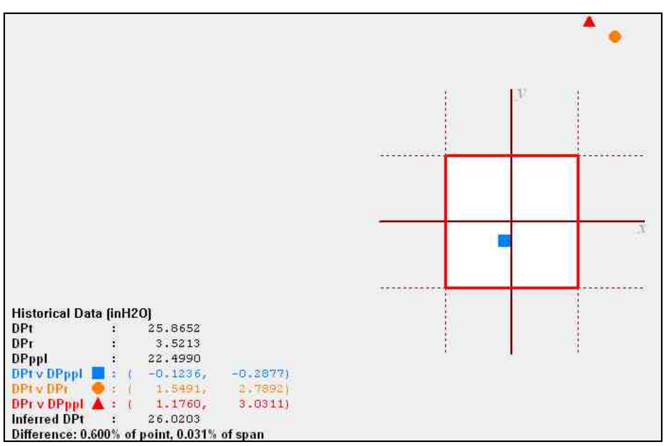


Figure 10 - Audit's sample representative Prognosis screenshot

The DP reading diagnostic check indicates that the DPs are being read correctly, with a 0.60 % difference being noted between the inferred and the read traditional DP. This is lower than the nominal 1% DP reading warning threshold. However, Prognosis is also showing that two out of the three diagnostic points are outside the NDB. Hence, Prognosis is stating that the meter has a problem with the meter body. Furthermore, as always, the particular pattern of the diagnostic plot gives more information. The pattern was relatively steady, so the problem was known **not** to be an unsteady flow problem (such as the unsteady wet gas flow or pulsation). Furthermore, from experience, this pattern suggests the bias is probably a steady negative error. The source of such errors can be short listed. This list was incorrect inlet or orifice diameter, distorted flow pattern, worn plate, buckled plate or contaminated metering run. A simple check of the meter geometry discounted any geometry error. The Prognosis result was therefore that the meter was in error, probably due to a distorted flow pattern, a damaged plate or contaminated meter run.

Again, due to contractual obligations, the auditors continued with the audit procedure. On this occasion, the orifice meter flow rate reading was approximately 10% lower than the clamp-on USM flow rate reading. This stated that one (or both) of these meters has malfunctioned. This is not a declaration that the orifice meter is necessarily under-reading the actual flow rate by 10%. This simply says the two meters disagree by that amount. The problem is as yet unknown so the effect on each meter is as yet unknown.

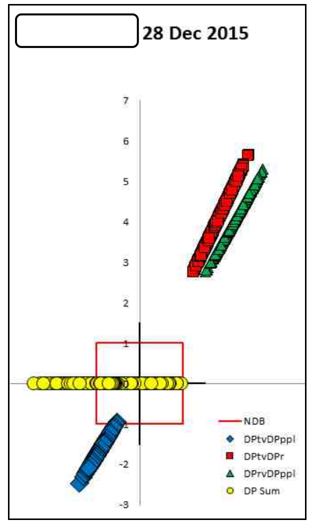
The meter was taken off-line (i.e. interrupted operations) to remove the plate for inspection and to borescope the meter run and flow conditioner. The DP transmitter was also checked. Figure 11 shows a photograph of the plate. The plate was contaminated. A subsequent borescope investigation of the meter run showed meter run contamination.

Figure 11 – Plate inspected during audit #2

Contaminated orifice meter runs produce negative errors on the meters flow rate output. Therefore, again Prognosis had correctly diagnosed that the meter had a problem and the problem was not with the DP readings but the meter body itself. Furthermore, the contamination and a negative bias error had been correctly shortlisted. The follow on auditor procedures of checking the DP transmitter and installing a clamp-on USM check meter were superfluous time consuming and costly additional procedures. If the operator had had Prognosis permanently installed on this meter the build-up of contamination would have been visible as it caused the diagnostic points to drift away from the centre of the NDB over time. This again, is evidence to why Prognosis should be thought of as a permanent installation with a DP meter.

EXAMPLE 5: 3 x 4" ORIFICE, OFFSHORE UK WEST OF SHETLAND

The DP meter validation system was installed offshore to monitor three 4", 0.51β orifice meters. Following initial start-up, the Operator was aware of process issues causing liquid contaminates to be present; this issue was in turn causing blockages in the DP Transmitter impulse lines. The Technician on site reported the effectiveness of the 'Prognosis' system which he observed to be in alarm prior to clearing the transmitter impulse lines, after which all alarms cleared.



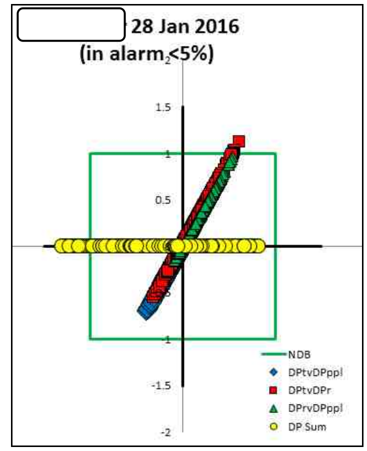


Figure 12 (Left) - Multi-data plot showing response during a problem period

Figure 13 (Right) - Multi-data plot showing alarms cleared

Figure 12 (left) shows multiple data from a 24 hour period where impulse line blockages were present. Figure 13 (right) shows multiple data from a 24 hour period one month later, when no impulse line blockages were present. As periodic unstable process conditions are evident in Figure 13 (like many production flows, the flow periodically fluctuating causes transient short lived alarms) the Operator may wish to reduce sensitivity settings in order to see no alarms during these periods. However, as the validation system screen is observed frequently on site rather than alarms being monitored intermittently remotely, the Operator preference is to keep the 'default' sensitivity settings in order that the system may be as responsive as possible to sustained problems re-occurring. This system then provides the Operator with real-time and helpful information on the performance of the meter system. That is, the system is flexible to any user's preference and needs.

As the site Technicians are able to observe the validation system response in real time on a dedicated monitor in the control room, they are able to identify when it may be necessary to perform corrective action (e.g., blowing down impulse lines) and when no such action is required. This is an example of Condition Based Maintenance (CBM) in action.

EXAMPLE 6: RUSSIAN FLARE GAS METER

Figure 14 – Polar Lights 4" paddle plate orifice meter with diagnostics installed

As part of the process to attain GOST approval in Russia, a Prognosis trial was arranged at the ConocoPhilips / Rosneft Polar Lights field. The test meter was a 4" paddle plate orifice meter in a flare gas application (see Figure 14). The available downstream tap was at 6.9D downstream of the plate, i.e. 0.9D downstream of the ideal location. The standard correction factor for the excess pipe length was applied, with an assumption made that the inside pipe condition was typical good quality pipe roughness. The Prognosis software was expanded to include the GOST orifice meter coefficients. The meter under test was assumed to be fully serviceable.

Testing took place in January 2014. The Prognosis software received from the flow computer the listed meter geometry (of inlet diameter of 102.26mm and orifice diameter of 44.45mm). The pressure of 2.4 Bar(a) and temperature of 71^{0}C produced a gas density of approximately 2 kg/m^3. The Prognosis operators chose to use default sensitivity settings. Figure 15 shows the initial Prognosis response.

The diagnostics indicated a significant error. The DP check was indicating the DP readings were correct. A list of potential problems that could cause that diagnostic pattern was listed. This included the comment that the orifice diameter may actually be lower than stated in the calculations. The plate was pulled and measured. It was discovered that the true inlet diameter was not 44.45mm as stated in the flow computer, but 38.1mm (i.e. the true beta ratio was 0.3726, not the stated 0.4347).

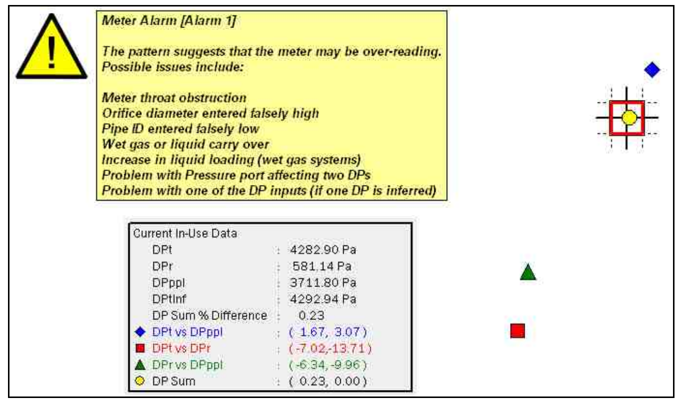


Figure 15 - Prognosis response at Polar Lights with flow computer geometry used

The archived Prognosis data was re-run using the correct orifice diameter. Figure 16 shows the shift in the diagnostic response. Although the diagnostics points are now much closer to the origin there is still a clear alarm that the meter has a significant problem. As all other possible causes of this particular alarm were eliminated, the operator checked the meter run for contamination or other non-compliance. Figure 17 shows the views looking upstream and downstream.

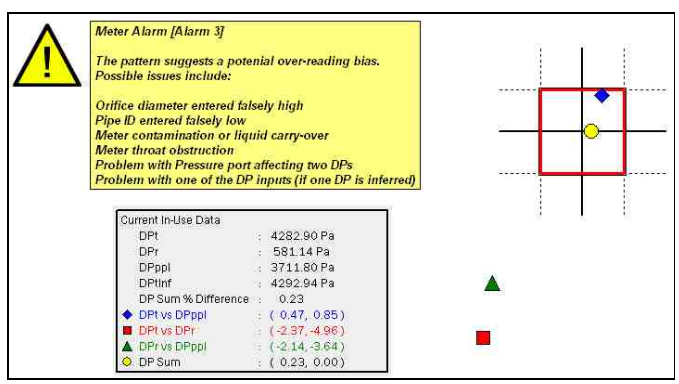


Figure 16 - Prognosis response at Polar Lights with corrected geometry used.

Figure 17 - Upstream (left) and downstream (right) meter run

The meter run is clearly not compliant with ISO 5167 nor GOST. There is significant weld beads and rust throughout the run. This will cause flow disturbance. DP Diagnostics has tested the effects of flow disturbances on orifice meters (e.g. Steven [2]) and the diagnostic plots presented are very similar to the pattern shown in Figure 17. The diagnostics were correctly indicating that the meter still had a problem.

The field test of Prognosis had been successful, although not in the way originally planned. This is proof that existing issues that are not even suspected will be detected by Prognosis on first application.

EXAMPLE 7: 2 x 20" ORIFICE METERS, ONSHORE UK GAS TERMINAL

The Operator of a UK onshore gas terminal applied the DP Meter validation system to two new, 0.65β orifice meters in order to verify good meter performance and reduce associated maintenance activities.

The initial system response indicated a problem. The response showing an alarm was extremely steady and repeatable. Figure 18 shows an example of historical data recorded at the beginning of 2016. The first 'possible cause' of alarm offered by the system is incorrect geometry in use. It was confirmed that there was no error in meter geometry in use but that the problem was most likely due to a small amount of liquid present in the gas. This has subsequently been advised by the Process engineers to be the case and was the next 'possible cause' of alarm offered by the system.

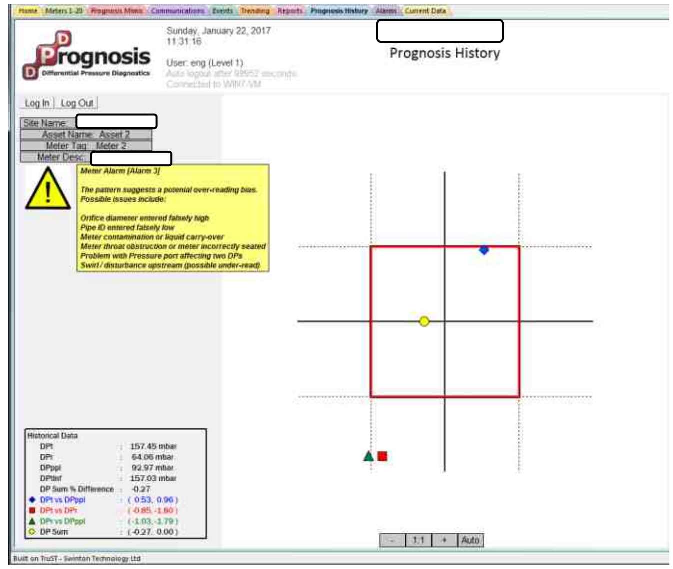


Figure 18 – Typical system response

A suitable 'Z Factor' for each meter was offered by the system which would adjust the expected 'baseline' meter performance to accommodate the observed process condition.

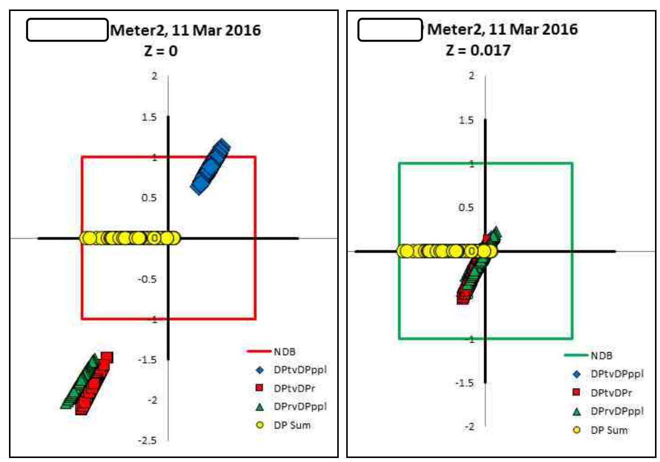


Figure 19 – Multiple data plots (24 hour period). Left: Original baseline settings, Right: Baseline adjusted to allow for known problem of trace liquid

Figure 19 shows two plots of the same set of data recorded over a 24 hour period. The left hand graph has original (default) baseline settings, the right hand graph includes a 'Z Factor' input of 0.017 (suggested by the verification system) which adjusts the expected meter performance to allow for the known problem of that amount of trace liquid presence. This Z-factor is only valid for the liquid loading at the time it was set. If the liquid loading subsequently increases or decreases this set Z factor will be too small or too large respectively. The points will again move outside of the box, thereby indicating a change in conditions, and whether the change is increasing or decreasing liquid loading. The Operator may now be confident that if the amount of liquid increases or decreases it will be obvious from the 'Prognosis' result.

Subsequent monitoring showed new alarms were observed indicating a DP Integrity issue. It was apparent that these 'DP Integrity' alarms were due to very low DPr and DPppl values relative to the respective DP transmitter ranges. Both the DPr and DPPppl transmitters were ranged 0-500mbar. Figure 20 shows both DPr and DPPppl at below 20 mBar and the DP Integrity alarm present.

The DPr Transmitter output will understandably have a relatively high uncertainty when measuring at the lower 3% of the calibrated transmitter range (URL 500 mBar). The alarm text states that the DPr input is untrustworthy.

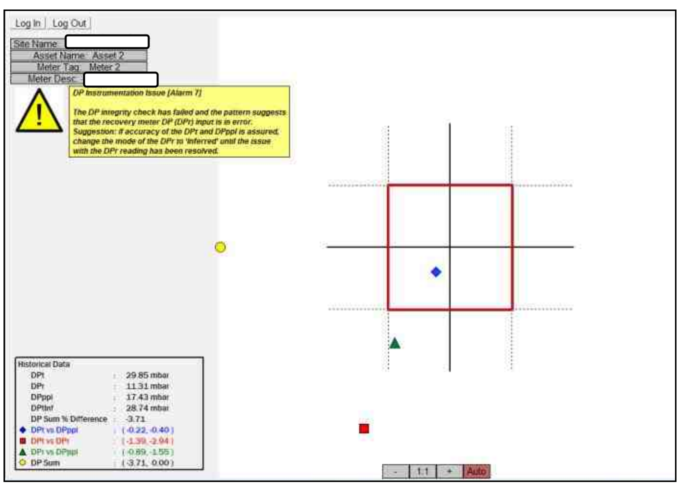


Figure 20 – DP Integrity Alarm with DPr and DPppl < 20mbar

Figure 21 shows the system response with the DPr set to 'Inferred', i.e. the measured DPr is replaced by the DPr inferred from the other two trustworthy DP inputs (see equation 1). The alarm clears, confirming that the measured DPr is the cause of the observed alarm.

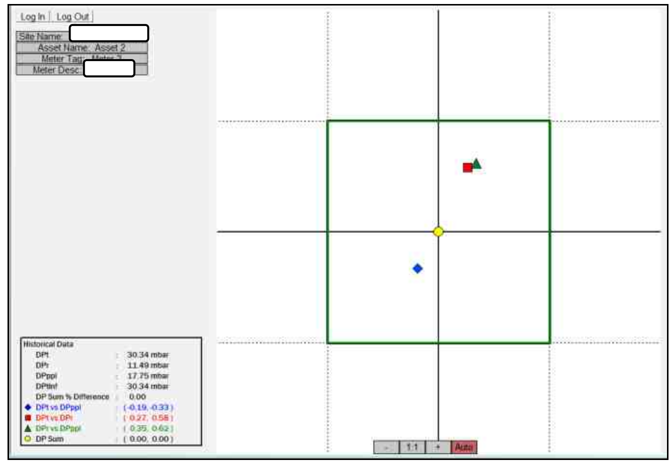


Figure 21 - Inferred DPr when DPr and DPppl < 20mbar

As discussed in previous sections, it is possible for the end user to adjust sensitivity and alarm settings which will inhibit alarms due to DP uncertainty at very low flows. In this case however, as the measured DPr and DPppl do not exceed (and are not expected to exceed) 200mbar and 150mbar respectively the Operator decided to re-range these transmitters in order that higher sensitivity to real problems be retained at lower flows. This example highlights the importance of ranging DP transmitters appropriately to the application. Properly ranged DP transmitters minimize the flow rate prediction uncertainty, and maximize both the meter's flow range and the range covered by the verification system.

EXAMPLE 8: 3 x 12" ORIFICE METERS, UK POWER STATION

Prognosis was installed on three 12" orifice meters at a UK natural gas fuelled power station. The power station has the capacity to generate 1,200 MW, of which 100 MW is allocated to supply the adjacent Chemical Park. The valuable by-product of 240 tonnes/hour of steam is sold to the Chemical Park to use in their process. This makes the power station one of the most efficient power stations in the UK. The natural gas to fuel the power station is metered by an Above Ground Installation (AGI). Within the AGI are 5 gas orifice metering streams; three 50% streams and two smaller 10% streams. Under normal operation gas flows through two of the (12”) 50% streams.

The operator had been experiencing orifice plate fouling, possibly due to compressor oil carryover and were aware that Prognosis would monitor for such issues. In 2014 Prognosis was installed on the three 12” orifice meters to allow a condition based monitoring approach. The Prognosis system installation was part of a metering computer system upgrade.

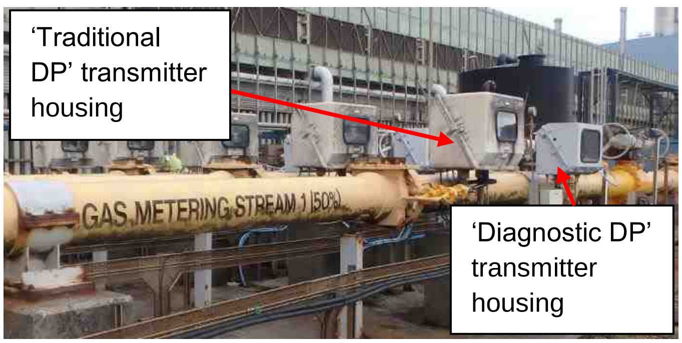


Figure 22 - AGI gas metering skid with instrument enclosures

Figure 22 shows stream 1 of the 5 stream metering skid (with the other 4 streams behind). The instrument enclosures housing the traditional meter DP Transmitters (medium and high range) and the ‘diagnostic’ DP Transmitters (DPr and DPppl) are indicated. Meters 2 and 3 have the same instrumentation arrangement with all DP readings accommodated in the stream flow computers.

The Prognosis software was integrated with the metering supervisory computer in order that diagnostic alarms be produced from the MSC and data was acquired from flow computers via Modbus.

The position of the available downstream pressure tap was further downstream than the standard 6D so the standard Prognosis correction for the additional pressure loss was duly applied.

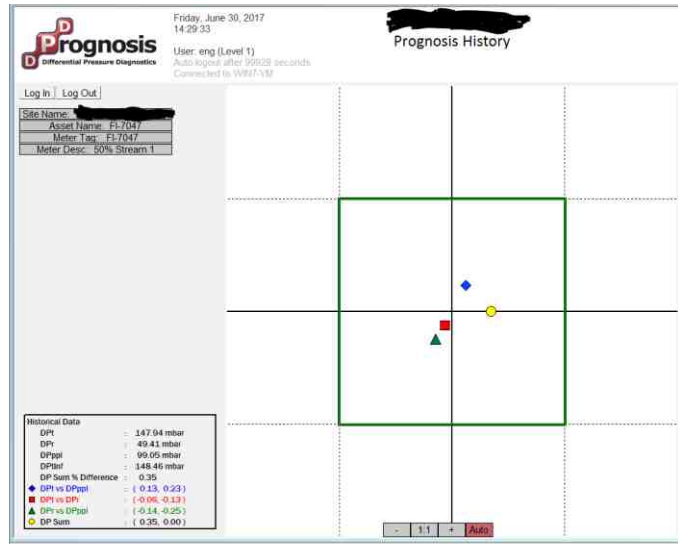


Figure 23 - Meter 1 typical Prognosis response

Figure 23 shows a typical response observed for meter 1. This data was recorded in April 2014 and the result was observed to be stable over time. During this test period the flow rates slowly varied between 9 to 18 kg/s (i.e. the DPt ranged from 60 to 211 mbar). The actual meter performance matches the expected meter performance and no alarms were raised (i.e. no points lay outside of the box).

However, both meters 2 and 3 initially saw problems, inclusive of ‘DP Integrity’ issues; that is the ‘DP Summation’ diagnostic check indicated a problem. The ‘inferred DPt’ (i.e. the sum of the DPr and DPppl) was higher than the measured DPt by >60%. Figure 24 shows Meter 3’s typical response during the period of ‘DP Integrity’ alarm. Meter 2 was very similar. This states there was a problem with the DP readings, and suggests that the problem was with more than one DP transmitter.

In this real example, the standard Prognosis suite states that the DP readings are wrong. On investigation GDF found that the Meters 2 and 3 had incorrect scaling applied to the recovered and PPL DPs. On correction, Meter 2’s diagnostic response showed the metering system was operating correctly. However, Meter 3’s standard Prognosis response still showed a smaller but still significant DP integrity alarm. Figure 25 shows the observed Meter 3 response.

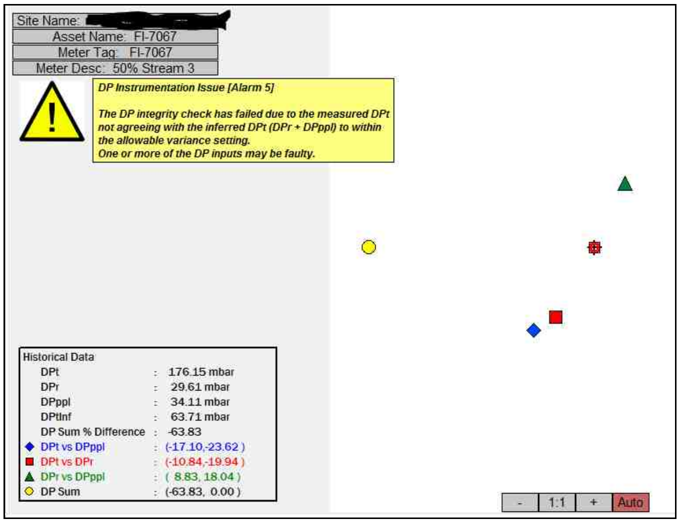


Figure 24 - Meter 3 initial response showing DP integrity error (Meter 2 similar)

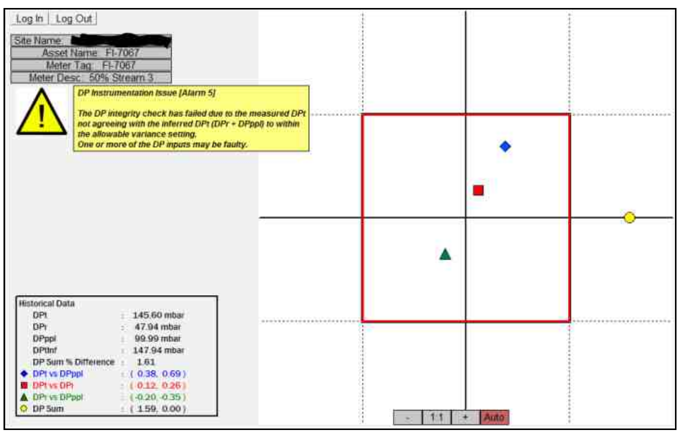


Figure 25 - Meter 3 Prognosis response following DP scaling correction

The 'DP Sum' diagnostic result of +1.6 means that the measured DPt is 1.6% lower than the sum of the measured DPr and DPppl. If the traditional DP was under-read by -1.6%, then the flow rate would be under-predicted by -0.8%. Investigation found a wiring issue in the instrument panel which was causing a small bias in DP measurements being received by the flow computer (and subsequently by Prognosis). Figure 26 shows the diagnostic response once this issue was rectified. The diagnostic response shows a healthy meter.

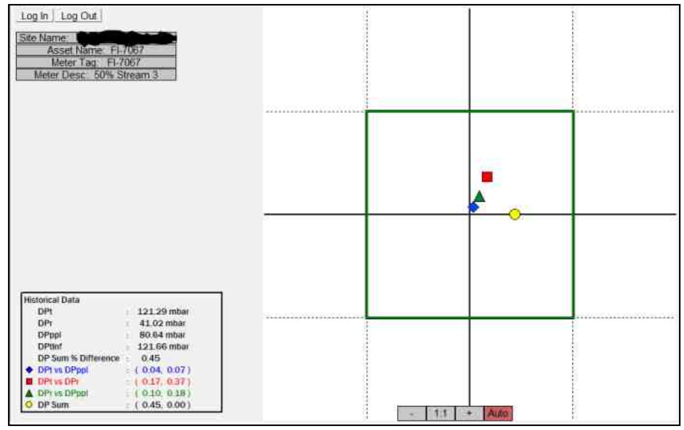


Figure 26 - Meter 3 Prognosis response over 2 hours following correction of DP integrity issue

This example shows that GDF made a reasonable decision to install Prognosis on these three orifice meters. Prognosis correctly identified a real world problem with the DP measurement. This DP error on Meter 3 would have resulted in a small but significant long term metering error that is unlikely to have been noticed without the presence of the diagnostic system.

SUMMARY AND CONCLUSIONS

Several examples of Operator field data have been shown including many normal cases where the 'Prognosis' DP Meter validation system provides valuable assurance on a daily basis of good meter system performance. This is the most common verification system result, i.e. it verifies the meter is serviceable. The system allows the Operator to adopt a Condition Based Maintenance strategy when it comes to meter inspections and DP Transmitter maintenance checks and calibrations.

In circumstances where a specific issue is suspected (e.g. wet gas flow), the validation system is able to confirm whether or not the meter does indeed have a problem or not. Only when a problem is registered does the Operator then have to intervene, or then use the validation tool as a trending tool until a permanent solution can be applied.

In cases where no adverse flow conditions are identified or suspected the Operator uses standard baseline and sensitivity settings as default. After experience is gained operating Prognosis on a specific meter, and there is confidence in that meter's serviceability, the Operator may choose to increase the sensitivity of the verification tool in order to see smaller problems as they arise in the future.

Where a specific issue is observed to be intermittent, the Operator can use the validation system to be alerted to that specific issue as it arises. The Operator then knows when remedial action needs to be taken and/or exactly when and for how long a significant mis-measurement occurs.

Where a specific ongoing issue is known and is being dealt with (e.g. wet gas is being corrected for), the Operator may adjust the 'Prognosis' baseline and sensitivity settings in order to monitor the issue with ease.

Operators without a comprehensive verification system are effectively operating 'blind'. Operators of DP meters who use these self-diagnostic / verification capabilities cease to operate 'blind' and benefit from real time ongoing validation, being alerted to potentially costly issues as they occur, and profiting from all the advantages of condition based maintenance.

NOTATION

β	Beta Ratio
D	Pipe Internal Diameter
DP	Differential Pressure
DPppl	PPL Meter DP
DPr	Recovery Meter DP
DPt	Traditional Meter DP
FPSO	Floating Production Storage and Offloading
ISO	International Organisation for Standardisation
NDB	Normalised Diagnostic Box
PLR	Pressure Loss Ratio (DPppl/DPt)
PPL	Permanent Pressure Loss
RPR	Recovery to PPL Ratio (DPr/DPppl)
PRR	Pressure Recovery Ratio (DPr/DPt)
Tx	Transmitter
URL	Upper Range Limit
USM	Ultrasonic Meter

REFERENCES

[1] Steven, R. "Diagnostic Methodologies for Generic Differential Pressure Flow Meters", North Sea Flow Measurement Workshop, October 2008, UK.

[2] Steven, R. "Significantly Improved Capabilities of DP Meter Diagnostic Methodologies", North Sea Flow Measurement Workshop, October 2009, Norway.

[3] Skelton, M., Barrons, S., Ayre, J., Steven, R. "Developments in the Self-Diagnostic Capabilities of Orifice Plate Meters", North Sea Flow Measurement Workshop, October 2010, UK.

[4] Rabone, J., Bryce, A., Morrison, M., Vajay, D., Glover, B., Steve, R. "DP Meter Diagnostic Systems – Operator Experience", North Sea Flow Measurement Workshop, October 2012, UK.

[5] Ayre, J., Glover, B., Hafidz, M., Steve, R. "Developments in Venturi Meter Diagnostics for Dry and Wet Gas Flows", South East Asia Flow Measurement Conference, March 2012, Malaysia.

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Number of Papers Published in Journals: 1

Number of Papers Published in Conferences: 10 (authored and co-authored)