3rd Party Manufactured Diagnostic Ready Cone Meter Performance Compared to Predictions of the New ISO 5167-5 Standard

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Abstract

The 2015 publication of ISO 5167-5 enables and encourages more manufacturers to produce cone DP meters. The performance of cone meters produced by new manufacturers can now be compared to the performance predictions of ISO 5167-5. Malaysian industry has long been a proponent of cone meters. Whereas traditionally Malaysian industry has only procured cone meters from foreign suppliers, the existence of the new ISO cone meter standard has been an aid for localized cone meter manufacture. In this paper the first Malaysian manufactured cone meters, i.e. two 20" and two 26" cone meters manufactured by Dermaga and calibrated at CEESI Iowa, are compared to the performance predictions of ISO 5167-5. These cone meters also have the DP meter verification / diagnostic suite 'Prognosis'. This paper reviews this diagnostic system and uses the CEESI calibration data to shows multiple examples of the diagnostic system is operation.

1. Introduction

Since the expiration of the cone meter patent in 2004 a few meter manufacturers have begun offering cone meters. However, many potential cone meter manufacturers hesitated building a meter where they had no previous experience and no standard to follow. Furthermore some end users do not like using a meter design that has no published standard.

The International Organisation for Standardization (ISO) Technical Committee (TC) 30 covers general flow metering technologies. ISO TC30 publishes ISO 5167 – the ISO standard on Differential Pressure (DP) meters. For many years this standard only covered general DP meter principles (5167-1), orifice meters (5167-2), Venturi nozzle meters (5167-3), & Venturi meters (5167-4). However in 2015 ISO 5167-5 [1] was published on cone meters.

The publication of ISO 5167-5 is a significant step in the wider acceptance of cone meters by industry. Furthermore, this standard will facilitate a wider number of DP meter manufacturers adding cone meters to their portfolio. One such company is Dermaga in Malaysia (aided by DP Diagnostics in the US). The Malaysian hydrocarbon production industry has long been a propoenent of cone meters but has historically procured them from overseas suppliers. Dermaga are the first local cone meter manufacturer and this endeavour has been in part aided by the pubication of this standard.

In this paper the performance of the first four cone meters manufactured by Dermaga and tested at CEESI Iowa is discussed. The performance is compared to the ISO 5167-5 performance predictions. Thes cone meters were calibarted and supplied with the DP Diagnostics / Swinton Technology 'Prognosis' meter verification suite. The performance of this verification suite is also discussed.

2. Cone Meter Operation

Cone meters are generic DP meters and therefore use the DP meter generic mass flow equation. Equation 1 shows this equation, where m is the mass flow rate, E & A_t are constant geometry terms, ρ is the fluid density, & ΔP_t is the traditional DP primary signal. The term ε is the cone meter expansion factor and is found by equation 2. Here P_1 & κ are the inlet pressure and the gases isentropic exponent respectively. β is the cone meter beta, a geometric constant as calculated by equation 3, where D & d_c are the inlet and cone diameters respectively. The discharge coefficient (C_d) is found by data fitting the calibration results to some function (f) to the Reynolds number, see equation 4. Equation 5 shows the Reynolds number expression, where μ is the fluid viscosity.

It is the cone meter specific expansion factor term (equation 2) and the value of the cone meters discharge coefficient (equation 3) that set the generic equation 1 specifically to the cone meter.

$$m = EA_t \varepsilon C_d \sqrt{2\rho \Delta P_t} \qquad (1)$$

$$\varepsilon = 1 - \left\{ \left(0.649 + \left(0.696\beta^4\right)\right) \frac{\Delta P_t}{kP_1} \right\} \qquad (2)$$

$$\beta = \sqrt{\frac{A_t}{A}} = \sqrt{1 - \left(\frac{d_c}{D}\right)^2} \qquad (3)$$

$$C_d = f(\mathrm{Re}) \qquad (4)$$

$$\mathrm{Re} = \frac{4m}{\pi \mu D} \qquad (5)$$

The DP meter mass flow rate prediction is found by iteration across equations 1 thru 5.

3. ISO 5167-5 Predictions

The new ISO standard gives geometry requirements for cone meters, and gives discharge coefficient predictions for meters with these geometries. Within the meter size and Reynolds number range of:

$$50 \text{ mm} \leq D \leq 500 \text{ mm}$$
$$0{,}45 \leq \beta \leq 0{,}75$$
$$8 \times 10^4 \leq Re_D \leq 1.2 \times 10^7$$

ISO predicted (in Clause 5.5.2) the discharge coefficient (C_d) to 0.82 ± 5% (i.e. $0.779 \leq C_d \leq 0.861$) at 95% confidence level. ISO commented that "The uncertainty of an uncalibrated cone meter is relatively high when compared to other ISO 5167 differential pressure devices. However, if a flow calibration is carried out the uncertainty in discharge coefficient is comparable to that of these other devices. Therefore, for applications requiring higher accuracy, it is recommended that every cone meter is calibrated over the full operational range of Reynolds number".

In Clause 5.9 ISO state that the pressure loss (Δω) across the cone meter is:

$$\Delta\varpi = (1.09 - 0.813\beta)\Delta P_t \qquad (6)$$

Dermaga manufactured these four large cone meters in accordance with ISO 5167-5. It is therefore important to Dermaga and ISO, and therefore to general industry, that cone meters made in accordance with the new ISO standard are found to behave within the performance specifications stated by ISO. These four cone meters were each calibrated at CEESI Iowa in August 2015. Each meter was calibrated across the applications full Reynolds number range as required by ISO 5167-5.

3. ISO Geometry Compliant Cone Meter Calibration Results Compared to ISO 5167-5 Predictions.

Figure 1 shows Meter 3, a 24", 0.669β cone meter before installation at CEESI Iowa. Figure 2 shows the meter installed in the CEESI Iowa natural gas flow line. Note that although the meters were not ordered with the Prognosis meter verification system Dermaga and DP Diagnostics still logged the diagnostic system data during the calibrations. Figure 2 shows that the downstream spool has a pressure tap and CEESI Iowa read the recovered and PPL DPs along with the traditional DPs. This information also allowed the pressure loss to be found and compared to the ISO prediction. For all four meters the downstream pressure tap used was located at five pipe diameters downstream of the cone element, and was therefore just slightly closer to the cone than the ISO 5167-5 permanent pressure loss (PPL) prediction (i.e. equation 6). This should have a minimal effect on the pressure loss prediction.

Figure 3 shows the CEESI Iowa calibration results for all four meters. Figure 3 also shows the ISO predictions of a Cd of 0.82 ± 5% with the limits of these borders.

Fig 1. Dermaga / DP Diagnostics 24" Cone Meter

Fig 2. Dermaga / DP Diagnostics 24" Cone Meter Under Calibration at CEESI Iowa.

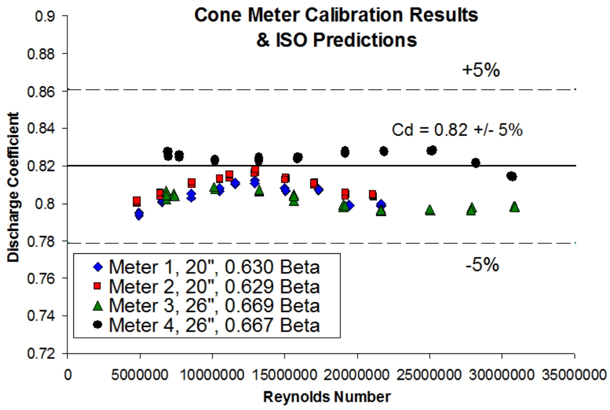

Fig 3. All 4 Cone Meter Calibration Results

Clearly the Dermaga cone meters built according to the ISO specified geometry have discharge coefficient values that fall within the ISO predictions.

Each of the four cone meter's discharge coefficient vs. Reynolds number relationships were data fitted to a second order polynomial (although other forms of data fitting work just as well). The resulting discharge coefficient predictions all had uncertainties of 0.5% to 95% confidence across the applications Reynolds number range. ISO 5167-5 does not specify a required discharge coefficient uncertainty but rather says "if a flow calibration is carried out the uncertainty in discharge coefficient is comparable to that of these other devices". It is notable that the orifice meter discharge coefficient uncertainty quoted by ISO 5167-2 is 0.5%, i.e. the same as these calibrated cone meters. Again, the results of testing these ISO 5167-5 geometry compliant cone meters was that the performance was as specified by ISO.

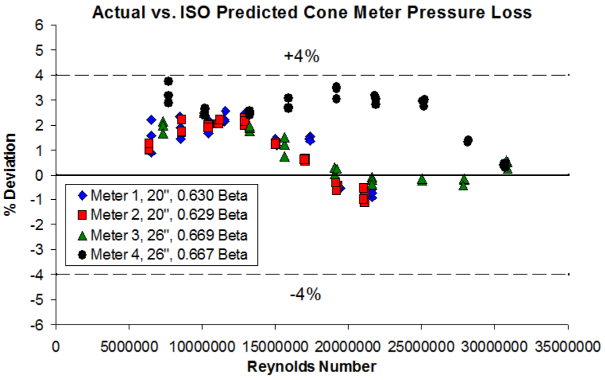

Fig 4. Actual vs. ISO Predicted Pressure Loss.

Figure 4 shows the results of analysing the four cone meter's permanent pressure loss. ISO 5167-5 gives a prediction (equation 6) but does not offer an associated uncertainty. Figure 4 shows the percentage deviation between each meter's actual pressure loss and the ISO prediction. ISO 5167-5 has predicted the actual loss to within 3.5% uncertainty at 95% confidence. This is surprisingly accurate for an equation ISO calls 'approximate'. This equation will be used in practice to predict an approximate pressure loss for pipe line hydraulic losses and this uncertainty is easily acceptable to such calculations, in fact it is a lot more accurate than the pressure loss predictions for many other pipeline components.

4. Cone Meters & the DP Meter Verification System 'Prognosis'

DP Diagnostics created a DP meter verification system called 'Prognosis'. Prognosis operates on all DP meters inclusive of cone meters. An overview of this 'pressure field monitoring' diagnostic system is now given. For details the reader should refer to the description given by Rabone [2], Steven [3], & Stobie [4].

Figure 5 shows a sketch of a generic DP meter and its pressure field. The DP meter has a third pressure tap downstream of the two traditional pressure ports. This allows three DPs to be read, i.e. the traditional (ΔP_t), recovered (ΔP_r) and permanent pressure loss (ΔP_{PPL}) DPs. Note that the verification system denotes the PPL DP as 'ΔP_{PPL}', while ISO 5167-5 denotes the same value as '$\Delta\omega$'.

These DPs are related by equation 6. The percentage difference between the inferred traditional DP (i.e. the sum of the recovered & PPL DPs) and the read traditional DP is $\delta\%$, while the maximum allowed difference is $\theta\%$.

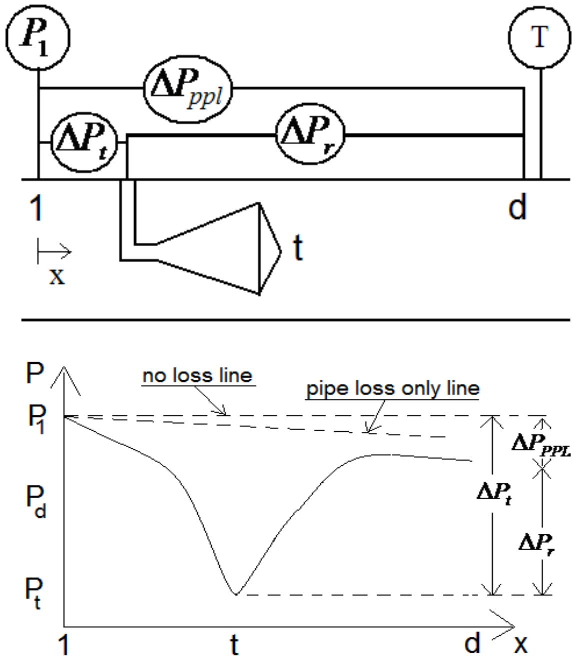

Fig 5. Cone meter with instrumentation sketch and pressure field graph.

$$\Delta P_t = \Delta P_r + \Delta P_{PPL} \quad \pm\,\theta\% \qquad \text{--- (6)}$$

Traditional flow calculation:

$$\dot{m}_t = EA_t \varepsilon C_d \sqrt{2\rho\Delta P_t} \quad \pm\,x\% \qquad \text{--- (1)}$$

Expansion flow calculation:

$$\dot{m}_r = EA_t K_r \sqrt{2\rho\Delta P_r} \quad \pm\,y\% \qquad \text{--- (7)}$$

PPL flow calculation:

$$\dot{m}_{ppl} = AK_{PPL} \sqrt{2\rho\Delta P_{PPL}} \quad \pm\,z\% \qquad \text{--- (8)}$$

Each DP can be used to independently meter the flow rate, as shown in equations 1, 7 & 8. Here $\dot{m}_{trad}$, $\dot{m}_{\exp}$ & $\dot{m}_{PPL}$ are the mass flow rate predictions of the traditional, expansion & PPL flow rate calculations with $x\%$, $y\%$ & $z\%$ uncertainties respectively. A is the inlet area and Kr & Kppl are the expansion & PPL coefficients respectively. Comparing 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 sum 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. That is, we can plot (see Figure 6) the following four co-ordinates to represent the seven diagnostic checks:

$$(\psi\%/\phi\%, \alpha\%/a\%), (\lambda\%/\xi\%, \gamma\%/b\%),$$
$$(\chi\%/v\%, \eta\%/c\%) \ \& \ (\delta\%/\theta\%, 0).$$

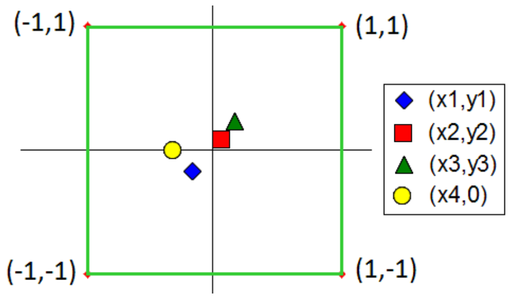

Fig 6. Normalized Diagnostic Box (NDB) with diagnostic results

For simplicity we can refer to these points as (x_1,y_1), (x_2,y_2), (x_3,y_3) & $(x_4,0)$ respectively. The act of dividing the seven raw diagnostic outputs by their respective uncertainties is called 'normalisation'. A Normalised Diagnostics Box (or 'NDB') of corner coordinates (1,1), (1,-1), (-1,-1) & (-1,1) can be plotted on the same graph (see Figure 6). This is the standard user interface with the DP meter verification system 'Prognosis'. All four diagnostic points inside the NDB indicate a serviceable DP meter, i.e. the meter's correct performance is verified. One or more points outside the NDB indicate a meter system malfunction.

Figure 2 shows Meter 3 (S/N 151010) with a downstream tap being calibrated to be diagnostic ready. Meter 3 will be used here as the randomly selected cone meter to show the diagnostic results. Figures 7 & 8 show the full Meter 3 Prognosis baseline calibration results from CEESI Iowa. (The other three meters had similar typical diagnostic calibration results not shown here due to space limitations.)

Figure 8 shows the PLR value. Note that this is defined as $\Delta\omega/\Delta P_t$, i.e. this is the actual calibration precise data fit of the approximation given by ISO's equation 6. The PLR is actually a function of beta ***and*** Reynolds number, which is why ISO state in 5167-5 Clause 5.9: "The pressure loss, *Δω*, for the cone meter described in this part of ISO 5167 is ***approximately*** related to the differential pressure, *Δp…*". To find a more precise prediction the meter needs to be calibrated across the applications Reynolds number range and the PLR data fitted.

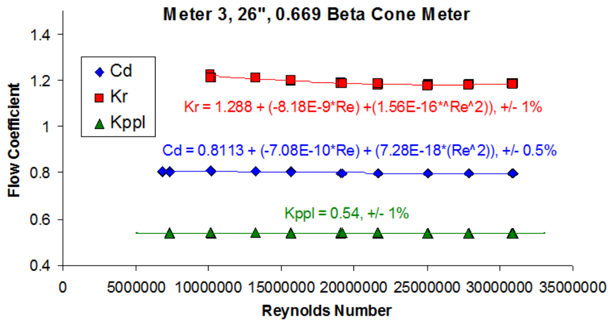

Fig 7. Meter 3 Flow Coefficient Calibration Results

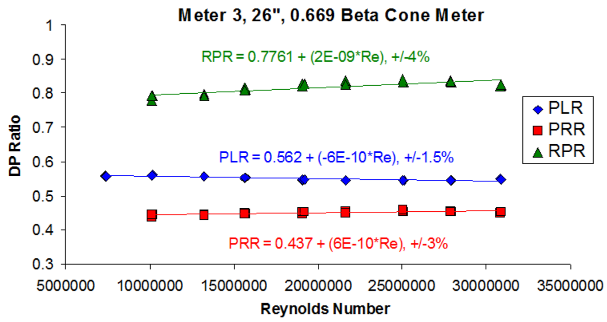

Fig 8. Meter 3 DP Ratio Calibration Results

A sample Prognosis result from the calibration data (where the meter was obviously operating correctly) is shown in Figure 9. This is a trivial result as the cone meter diagnostic system was calibrated to this data. A far more interesting exercise is to take this data set and carry out desktop exercises to simulate how the meter verification system will react if it is later given a problem.

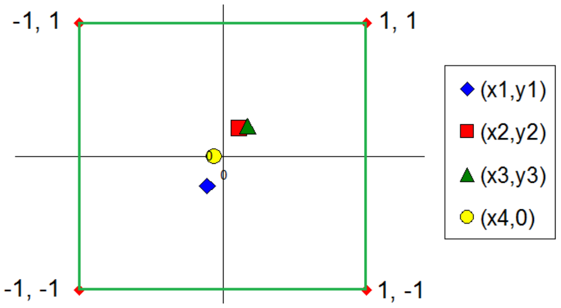

Fig 9. Meter 3 Prognosis Sample Point

4a. Cone Meter Prognosis Examples

The CEESI Iowa calibration data allows desktop examples of Prognosis in use to be created.

Switching Calibration Data Sets

It is common for multiple nominal identical flow meters to be manufactured and calibrated in a batch for one project. In such scenarios due diligence is normally the only safe guard against nominally identical meters having their respective calibration results accidentally inter-changed. If two nominally identical cone meters are found to have different discharge coefficient calibration results that are subsequently accidentally switched when entering the results to the flow computers this will result in both meters incorrectly metering the flow rate. Traditionally there is no method of identifying this issue.

Figures 10 & 11 show the Prognosis response of two cone meters (S/N 151010 & S/N 151011) when they have their respective calibration data accidentally switched (i.e. they are using the others discharge coefficient). The data point (used in all subsequent examples) had 69.5 bar(a) flowing at 93.7 kg/s. S/N 151010 would have a +2% gas flow rate prediction bias, while SN 151011 would have a -1.6% bias. Whereas this would normally go unnoticed Prognosis shows a problem exists (see Figs 10 & 11).

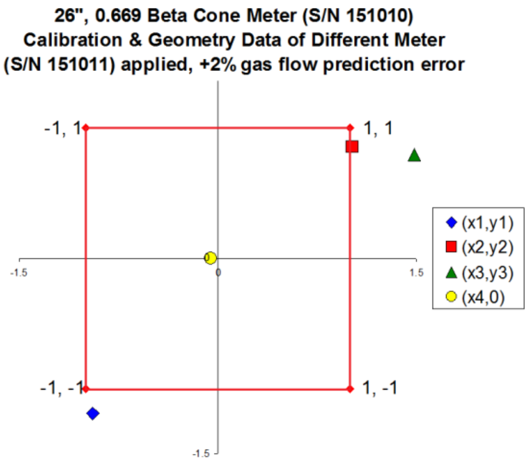

Fig 10. Prognosis Response of Cone Meter (S/N 151010) with Cone Meter (S/N 151011) Erroneous Calibration Data Applied.

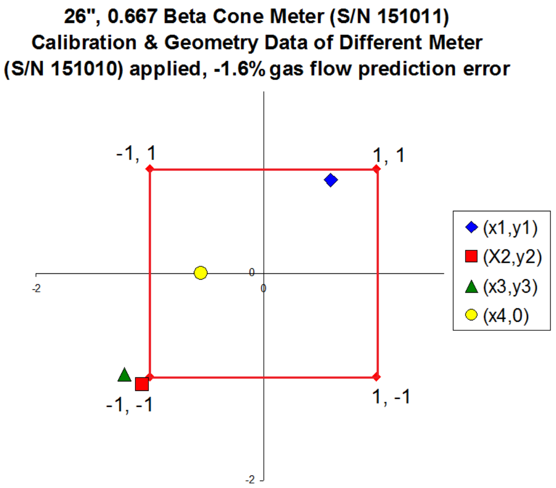

Fig 11. Prognosis Response of Cone Meter (S/N 151011) with Cone Meter (S/N 151010) Erroneous Calibration Data Applied.

Incorrect Keypad Entry of Inlet Diameter

Equation 1 is the generic DP meter flow rate equation. The throat area A_t is a critical component of that equation. The orifice, nozzle, Venturi nozzle & Venturi meters all have circular throats of diameter ‘d’. Hence the flow rate calculation of these common circular throat DP meters is very sensitive to the keypad entry of the throat diameter. However, the circular throat DP meter design’s flow rate prediction is rather insensitive to the keypad entry inlet diameter. The reason for this is that the inlet diameter of a circular throat DP meter is not used to calculate the throat area, and is only used to calculate the Velocity of Approach, E (see equation 9). The Velocity of Approach is rather insensitive to inlet diameter errors.

$$E = \frac{1}{\sqrt{1-\beta^4}} \qquad (9)$$

A cone meter’s throat area is not circular but rather an annular ring calculated by the cone diameter **and** the inlet diameter. Hence, unlike the circular throat DP meter designs the cone meter’s throat area calculation and hence flow rate calculation (equation 1) is very sensitive to the meter inlet diameter input. Furthermore, a cone meter’s Velocity of Approach calculation is more sensitive to the inlet diameter input than that of a circular throat DP meter. Therefore, a keypad entry error in a cone meter’s inlet diameter produces a much greater flow rate prediction error than an equivalent error with a circular throat DP meter. What’s more, like the circular throat DP meter’s flow rate prediction high sensitivity to throat diameter inputs, the cone meter has similar high sensitivity to cone diameter inputs. It is these issues that led ISO 5167-5 to state in Clause 4:

“As the cone meter flow rate calculation is particularly sensitive to the pipe and cone diameter values used, the user shall ensure that these are correctly entered into the flow computation calculations. For example, care shall be taken to use the measured internal diameter rather than a nominal value.”

Traditionally there was no way to monitor for incorrect geometry value input. The operator had to rely on due diligence only. However, Prognosis can monitor for this problem.

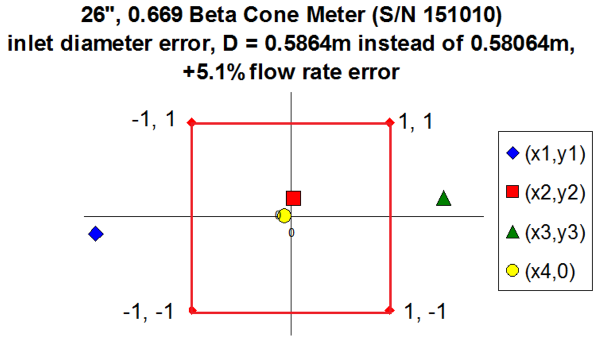

Fig 12. Prognosis Response of Cone Meter with Incorrect Inlet Diameter Keypad Entry.

Figure 12 shows the result of a desktop exercise where a cone meter having been correctly calibrated to set the Prognosis baseline at CEESI Iowa subsequently has a wrong inlet diameter keypad entered into the flow computation. In this example, note that a 1% error in inlet diameter produces a 5.1% bias in flow rate prediction. However, Prognosis shows a problem exists.

Incorrect Keypad Entry of Cone Diameter

Figure 13 shows a desktop exercise using the CEESI Iowa calibration Prognosis baseline where the meter has been installed in the field with an incorrect cone diameter entered into the calculation. Traditionally there was no way to monitor for incorrect geometry value input. The operator had to rely on due diligence only. However, Prognosis can monitor for this problem.

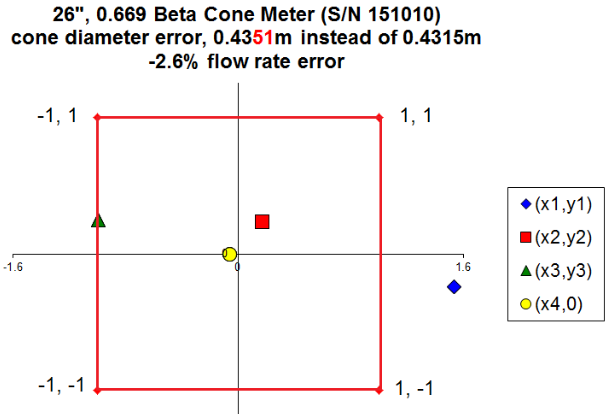

Fig 13. Prognosis Response of Cone Meter with Incorrect Cone Diameter Keypad Entry

Incorrect Keypad Entry of the Discharge Coefficient

Figure 14 shows a desktop exercise using the CEESI Iowa calibration Prognosis baseline where the meter is using an incorrect discharge coefficient (i.e. different to that shown in Figure 7). Traditionally there was no way to monitor for incorrect discharge coefficient input. The operator had to rely on due diligence only. However, Prognosis can monitor for this problem.

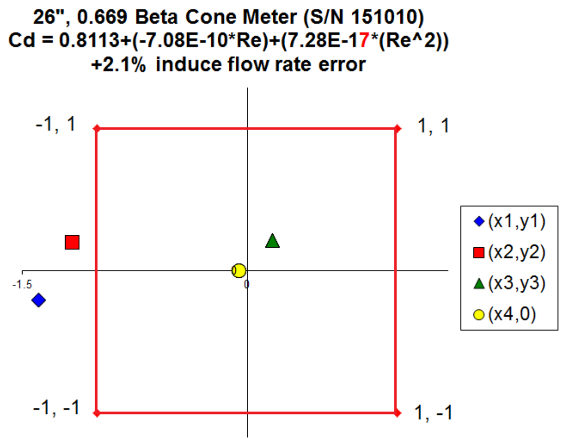

Fig 13. Prognosis Response of Cone Meter with Incorrect Discharge Coefficient Keypad Entry

Incorrect DP Read

Figure 14 shows a desktop exercise using the CEESI Iowa calibration Prognosis baseline where the traditional DP transmitter reading is erroneous. In practice this can be caused by a drifting DP cell, a saturated (i.e. over ranged) DP cell, an incorrectly calibrated 4-20 mA DP cell etc. (In this example we suggest the DP cell has drifted.) Traditionally there was no way to monitor for incorrect DP reading other than having duplicate DP transmitters. The operator typically had to rely on due diligence only. However, Prognosis can monitor for this problem.

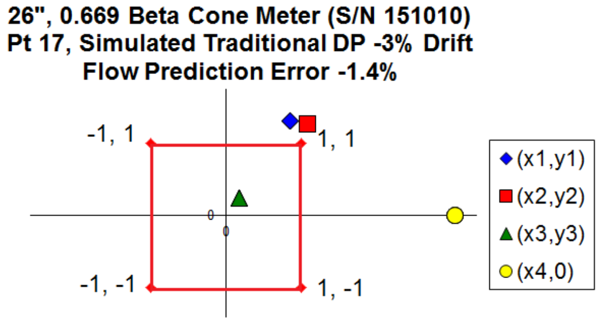

Fig 14. Prognosis Response of Cone Meter with Incorrectly Read traditional DP.

Here, the Prognosis pattern in Figure 14 not only shows that *something* is wrong, but suggests *what* is wrong. The diagnostics point x_4 is the DP integrity check. It is stating the DPs have a problem. It can then be noticed that the point (x_3,y_3) is inside the NDB while both (x_1,y_1) & (x_2,y_2) are both outside the NDB. As we know the problem is a DP reading problem (as x_4 is outside the NDB) we can deduce that as (x_3,y_3) does not use the traditional DP reading, whereas (x_1,y_1) & (x_2,y_2) both do, the problem is with the traditional DP reading, and hence the flow rate prediction is incorrect. Once this is deduced, as Prognosis is also showing the recovered & PPL DP readings are correct, i.e. (x_3,y_3) is inside the NDB, we know we can sum the recovered & PPL DP values and infer the correct traditional DP, and hence the correct flow rate. This is an example of Prognosis not only being a diagnostic / verification tool but offering over determination of outputs, i.e. a level of sub-system redundancy not otherwise available with traditional DP meter technologies.

Aside:

Section 3 talks about an uncalibrated cone meter having an ISO discharge coefficient of 0.82±5%. It is only after calibration that a cone meter performance has a flow rate prediction uncertainty < 1%. However, the designer of a cone meter must obviously choose the cone meter beta before the meter can be manufactured and then calibrated. The designer will have a target maximum DP for a given applications flow conditions, say for example 1 Bar / 400"WC. But the designer can only predict the discharge coefficient to ±5%. As flow rate is directly proportional to discharge coefficient, and has a parabolic relationship to DP (see Equation 1) this means that the designer can only estimate the maximum DP before calibration to ±10%. That is, if the designers assumed discharge coefficient (of 0.82 ±5% set by ISO) is off by -5%, then the corresponding DP will be off by +10%.

It is this issue that ISO 5167-5 Clause 5.7 is referring to when it states; "For a given flowrate, the uncertainty of the discharge coefficient and that of the predicted differential pressure are directly linked. Consequently, care shall be taken with determining β such that the maximum differential pressure does not exceed the upper range limit of the transmitter."

Most DP transmitters on the market can read up to approximately 8% above their stated maximum, which obviously doesn't cover the cone meter's potential +10%. Checking that the actual DP is not saturating the DP cell is therefore an important check when commissioning cone meters in the field. Whereas this issue has traditionally been dealt with by due diligence only, Prognosis can actively monitor for such a DP problem.

<u>The Diagnostic System Diagnosing Its Own Health</u>

So far all diagnostic / meter performance verification examples discussed have been with issues that cause the meter's flow rate prediction to be in error. However, the DP meter verification system has additional sub-systems, i.e. additional (recovered & PPL) DP transmitters and diagnostic parameters superfluous to the flow rate calculation (e.g. the DP ratios). Therefore, the DP meter verification system can experience issues that do not cause the primary meter flow rate prediction to be in error. A comprehensive diagnostic / verification system requires the ability to diagnose itself, i.e. also monitor its own sub-systems for problems. Prognosis has this ability.

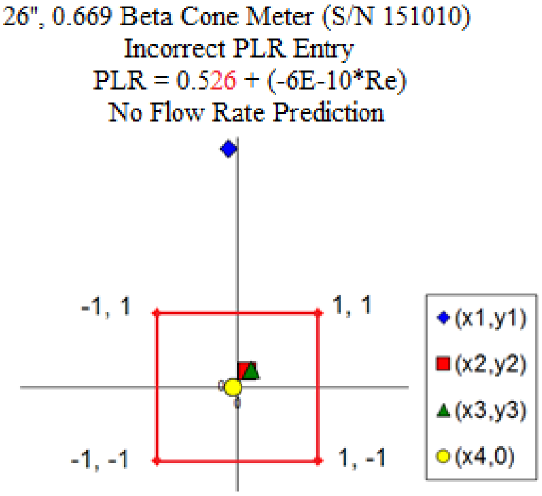

Fig 15. Prognosis Response of Cone Meter with Incorrect PLR Keypad Entry

Figure 15 shows an example of the Prognosis response if the calibrated PLR vs. Reynolds number relationship is entered to the system incorrectly. Note that the function has been incorrectly keypad entered (compared to the correct value shown in Figure 7). The Prognosis alarm is only due to $y_1 > 1$. All other meter performance verification checks are showing an operating meter. The DP integrity check shows the DPs are read okay. All flow rate comparisons (x_1, x_2, & x_3) indicate no problem. But most importantly, the other two DP ratio checks y_2 & y_3 indicate no problem. This result cannot physically be created as it would contradict the fact that equation 6 has been seen to hold. The only explanation is that the PLR baseline is incorrect.

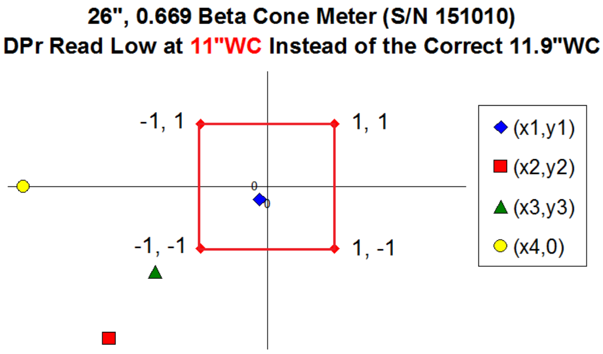

Fig 16. Prognosis Response of Cone Meter with Drifting Recovered DP Transmitter

Figure 16 shows another example of a Prognosis sub-system having a problem, but yet the cone DP meter is still operational. The DP integrity check (x_4) is stating the DPs have a problem. It can then be noticed that the point (x_1,y_1) is inside the NDB while both (x_2,y_2) & (x_3,y_3) are both outside the NDB. As we know the problem is a DP reading problem (as x_4 is outside the NDB) we can deduce that as (x_1,y_1) does not use the recovered DP reading, whereas (x_2,y_2) & (x_3,y_3) both do, the problem is with the recovered DP reading. As the traditional & PPL DPs are read correctly, and the diagnostic checks comparing these correct DPs show no problem, this states that the primary flow rate prediction is correct.

Both the incorrect PLR keypad entry and the drifting recovered DP examples are examples of the system checking its own health, i.e. self-diagnose its own sub-systems. In these cases the DP meter verification system correctly diagnosed that the problem is with the diagnostic system and not the meter. Such capability guards against false alarms.

7. Conclusion

The ISO 5167-5 standard on cone meters is published and being used by industry. The existence of this ISO document has aided Dermaga, the first meter manufacturer in Malaysian, to manufacture cone meters that can be proven to be of ISO acceptable design and performance. The four large cone meters manufactured by Dermega according to the geometry constraints of the ISO standard performed as ISO predicted. All four meters were found by calibration at CEESI Iowa to have a discharge coefficient that was within the ISO stated limit of 0.82±5%. Data fitting the discharge coefficient vs. Reynolds number (or linear point to point fitting) produced a cone meter with 0.5% discharge coefficient uncertainty at 95% confidence. Furthermore, all four cone meters were found to have a PLR to within 3.5% of the ISO prediction at 95% confidence. These results testify to Dermaga's ability to manufacture ISO compliant cone meters and show that the new ISO 5167-5 document is robust, i.e. accurate in its statements and predictions.

The DP Diagnostics DP meter verification tool 'Prognosis' was also shown to operate correctly. These Dermaga cone meters are now fully diagnostic capable and therefore these cone meters are some of the first cone meters in industrial service anywhere with the ability to have an internal real time comprehensive meter validation tool.

References

[1] ISO 5167-5: "Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full – Part 5: Cone meters".

[2] Rabone J. et al "DP Meter Diagnostic Systems – Operator Experience", North Sea Flow Measurement Workshop 2014, St Andrews, UK.

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