North Sea FLOW Measurement Workshop

Paper 6.3

Fiscal Oil Ultrasonic Meters: Introducing the Calibration Performance Monitoring (CPM)

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nel technology for life

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Introducing the Calibration Performance Monitoring (CPM)

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1 ABSTRACT

Off-site calibration of USMs is now considered in more and more applications and projects:

- The cost of a displacement prover is not acceptable for the project,
- The big size of the meter will lead to an unacceptable volume for the prover,
- Ultrasonic Master Meter is preferred, due to their unique features in terms of CAPEX / OPEX savings and to their wide operational range.

So securing the transition from calibration laboratory to field is of primary concern.

Thanks to their large number of ultrasonic beams, a new generation of meters give a rich and reliable access to quantitative, traceable and accurate information on the velocity profile inside the metering section.

From these data, a new validation method is built: the Calibration Performance Monitoring.

This new method is fully in phase with the API recommendation, which encourages users to monitor internal diagnostic parameters and to compare them to the lab determined ones.

It is valuable at every stage of the meter's life:

- at calibration time, to validate the installation
- at commissioning time, to validate the error of the meter
- as a powerful tool for periodic verification, to decide if a recalibration is necessary or not,
- as a real-time alarm tool, to protect the metering system against an unexpected chance in conditions between proves.

2 INTRODUCTION

Ultrasonic meters are in phase with the quick evolution of general instrumentation.
- Advances in material science: namely piezo-composite ceramics,
- Advances in mainstream electronics: power doubles every 18 months,
- Specific advances in medical ultrasonic imaging: components and algorithms.

Clearly, USMs have not exhausted their potential. Major trend for the future are:
- low power electronics,
- ultra-fast scanning rates,
- more ultrasonic beams.

1999 2008

As we will see, these advances have serious operational consequences.

3 FLOW TOMOGRAPHY: The Holy Graal?

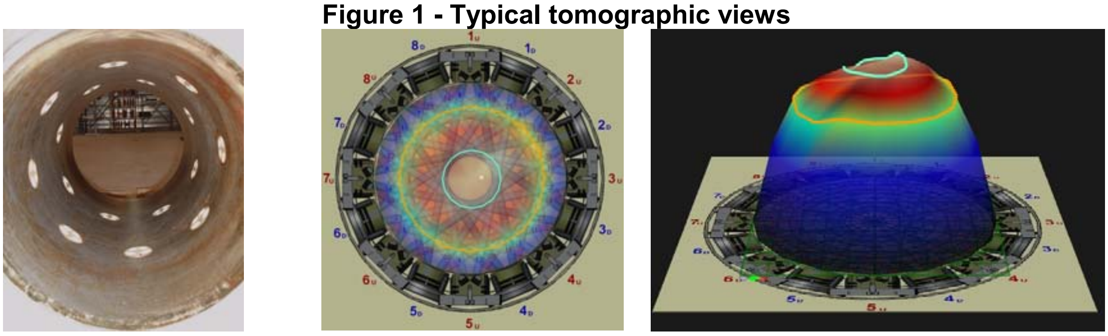
It is well known today: no USM can cover the full industrial range of flow profiles and Reynolds Numbers from naphtas to heavy oils by simply summing the velocity measurements over the acoustic paths ... at least not within a 0.15% accuracy.

So every meter needs some amount of "flow calibration".

With much more beams available, it could look reasonable to get rid of this costly "flow calibration" by tomographic techniques.

The basic idea of flow tomography is:
- to divide the metering section in M small cells
- to compute the velocity (Vi) in each cell from the velocities over the N paths (Uj)
- finally to sum all the cell velocities so as to get the flowrate

Figure 1 - Typical tomographic views



This is not the place to expose the theory of tomography, but an important result is to keep in mind : the solution of the tomographic problem (i.e. find the Vi from the Uj) is univocal if, and only if, M =N, i.e. number of cells = number of beams.

For example, a 32 beams will only solve exactly 32 flow cells, which is rather low resolution.

It is of course possible to get images with better resolution, but it does require some non-exact
numerical manipulations (modelling, extrapolations, ...)

Let's develop.

Vi = [A] Uj	V1 = a11 U1 + ,, + a1n Un	where :
	,,,	A is a [n*n] matrix.
	Vn = an1 U1 + ,, + ann Un	aij are constant coefs.

Flowrate is : Q = (Pi*D^2 / 4) (V1 + ... + Vn)
Q = (Pi*D^2 / 4) [(a11+...+an1) U1 + ... (a1n+...+ann) Un]

so, finally : Q = (Pi*D^2 / 4) (k1 U1 + .. kn Un) ...

... which is not more than <u>the weighted sum of the ultrasonic velocities !</u>

So, as far as the concern is to compute flowrate, a "honest" (assumption-free) tomographic method is not more that the weighted sum of the velocities ...
... unless we make some "assumptions" on the shape of the flow profile to be metered ...,
... but who would accept oil transactions based on " assumptions" ?

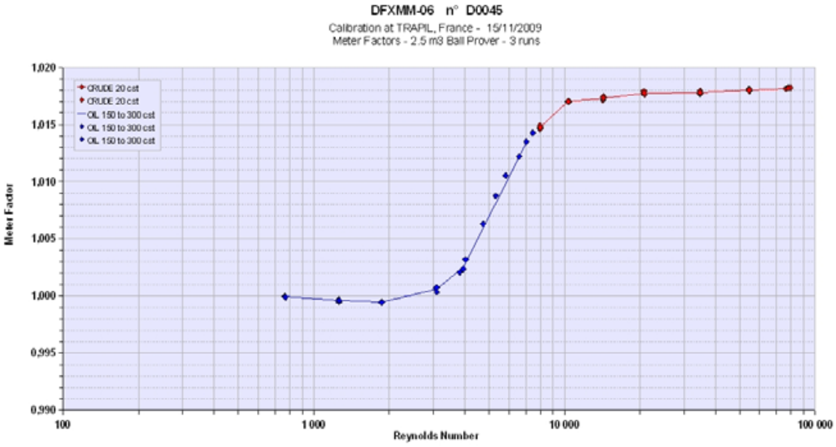
More seriously, tomography is probably the future of ultrasonic metering, but much further research is needed to make it acceptable at fiscal quality level.

We, at M&T, already have a foot in it and strongly encourage R&D on this topic.

4 LABORATORY CALIBRATION and its LIMITS

4.1 Flow Calibration Basics

Figure 2 - Typical error curve - uncalibrated 6"meter, 20 to 300 cst



Here is a typical "raw" error curve from an uncalibrated 6" USM over a wide viscosity range. ("raw" means : just the weighted sum of the path velocities).

Results could be slightly different with different path positions or different weighting coefficients, but overall shapes as above are well known from experience.

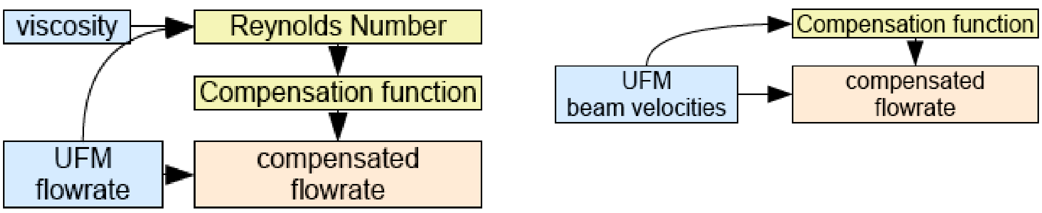
- linearity is fiscally acceptable for Reynolds Numbers (RN) above 10 000 (i.e. less than 20 cst in a 6" meter) and below 2 000 (more than 300 cst in a 6" meter)

- Meter Factor is shifted +/- 1% within the turbulent-to-laminar transition zone because of the drastic change in velocity profile. (for our 6" meter, this means from 20 to 300 cst, i.e. very common operating conditions).

So some kind of compensation is mandatory. Here are the classical methods :

Figure 3 - Flow calibration techniques

REYNOLDS-based PROFILE-based



- <u>Principle</u> :
Compensate the "raw" flowrate with an external knowledge of the Reynolds Number, so of the viscosity.

- <u>Advantage</u> : "transparency" :
Meter produces only "raw" data

- <u>Drawback</u> : unpractical :
need for accurate inline viscosity meter or viscosity/T°C model in flow computer

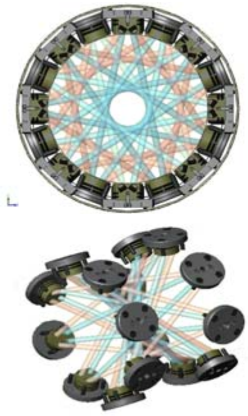
- <u>Principle</u> :
Compensate the meter using only the velocity measurements along the paths

- <u>Advantage</u> : practical, widely used
No need for external instrumentation

- <u>Drawback</u> : :
Installation conditions critical.
Need for a not-too-bad velocity profile

4.2 Profile-based Flow Calibration: a practical example

The meter is made of: - 16 BLUE paths located roughly at 0.25 R,
- 16 RED paths at 0.75 R.



Flowrate is : **$Q_{m3/h}$ = (3600*PI*D^2 /4) * (1/32) * Sum (Vi) * Calibration Function**

The meter is said "uncalibrated" when the Calibration Function is set to 1.000 .

The ratio " blue / red " velocities is used as an input for the calibration function.

Let's name it: PROFILE NUMBER (PN).

(Also know as 'shape factor', 'flatness ratio', ... but the concept is the same)

It is a non-linear function (f) of the Reynolds Number (RN) only.

It is computed and logged in real-time by the meter.

High Reynolds N° :
"flat" velocity profile
blue and red velocities give close results

Low Reynolds N°
"parabolic" velocity profile
blue over-count and red under-count.

In a similar way, the RAW METER FACTOR (RMF) of the uncalibrated meter is another non-linear function (g) of the Reynolds Number (RN) only.

From the (f) and (g) functions, we build a third function (h), which describes the RAW METER FACTOR (RMF) versus the PROFILE NUMBER (PN). .

This function (h) is <u>independent on the Reynolds Number</u> (RN).
It is the calibration function to be entered in the memory of the meter.

RMF = f (RN) + PN = g (RN) => RMF = h (PN)

Step #1 *:*

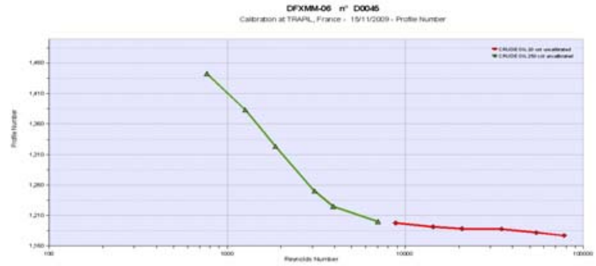
Proving to establish the
RAW METER FACTORS (RMF)
v/s Reynolds Numbers (RN)

Linearity is +/- 1% from 20 to 300 cst.

"raw curve" RMF = f (RN)

Step #2 *:*

simultaneously record the
PROFILE NUMBERS (PN).
(*BLUE*/*RED* *ratios)*
v/s Reynolds Numbers (RN)



"profile curve" PN = g (RN)

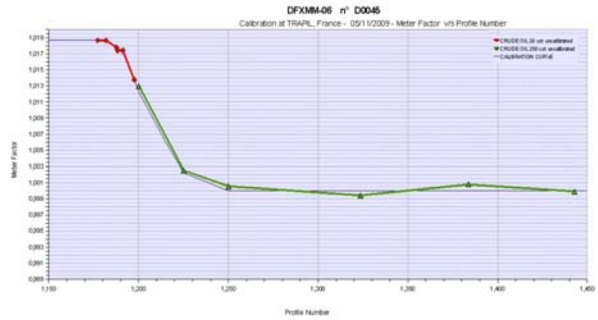
Step #3 *:*

Combining (f) and (g) so as to get

a third function (h) RMF = h (PN),

which is now independent on RN.

It is the CALIBRATION FUNCTION



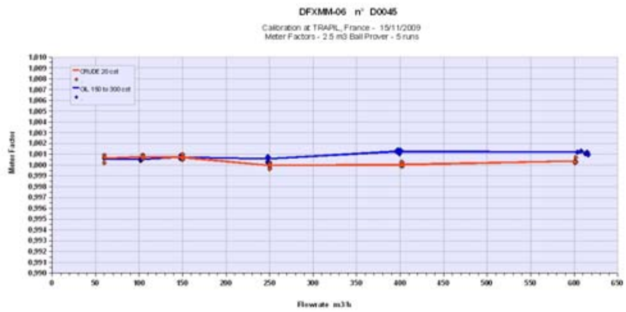
"calibration function"

RMF = f (RN) + PN = g (RN) => RMF = h (PN)

Step #4 *:*

Enter this curve (h) in the meter and prove for validation.

Linearity is +/- 0.1% from 20 to 300 cst.



4.3 Flow Laboratory Calibration: the limits

It is not exactly true that both the "raw curve" and the "profile curve" depend only on the Reynolds Number (RN).

Actually, they depend both on the RN and on the installation conditions.

And of course, installation conditions at final location will not match the lab ones,
each difference being a potential source of systemic error, with its own sensitivity coefficient.

Figure 4 - Possible differences from lab to field

" FAR UPSTREAM " conditions	- inlet geometry (elbow, tee, manifold) - valve - straight length - reducer angle - number and location of flanges - piping schedule & rugosity - intrinsical turbulence level ...
" NEAR UPSTREAM " conditions (between FC and meter)	- straight length - schedule & rugosity - orientation of Flow Conditioner - concentricity - gaskets ...

Even if most sensitivity coefficient are individually small, their sum may be significant:
ten independent errors as low as 0.1% will combine to give a 0.32% global error.

More problematic, undetected accidental errors are possible : protruding gasket, bad piping concentricity, misalignment of the flow conditioner,...

These sources of error are only evaluated in very rare "type approval" tests.

They are quasi-impossible to evaluate individually on a case-by-case basis :
- the final detailed geometry of the metering skid is often unknown at lab calibration time,
- we, manufacturers, have to confess that we sometimes accept situations where the meter is not calibrated using its final upstream piping.

As a consequence, it is a common practise of our industry not to document the effects of installation as seriously as necessary, and to consider that the overall effect is a small and constant shift of the Meter Factor from lab to field, which is detected and corrected at field proving time.

This policy is acceptable in a lot of situations, mainly when Reynolds N°s are greater than 10 000 or smaller than 2000.

But what if …?

Figure 5 - Some situations at risk when ignoring installation effects	
1	USM to be used as a MASTER METER
2	Reynolds N°s between 2 000 and 10 000 (for a 6" : 20 to 300 cst, for a 16" : 50 to 800 cst)
3	Accuracy / reliability of the proving device (displacement, master, tank) is less than the accuracy of the calibration lab
4	No Field Prover

These metering situations are obviously from the real world,

They are usual, as off-site calibration is now considered in more and more projects :

- The cost of a displacement prover is not acceptable for the project,
- The big size of the meter will lead to an unacceptable volume for the prover,

- Ultrasonic master meter is preferred, due to their unique features in terms of CAPEX / OPEX savings due to their wide operational range.

5 Taking ADVANTAGE OF MORE BEAMS

5.1 Axial Symmetry

The first obvious advantage of more beams is the high degree of symmetry, which minimizes the adverse effects of severe distorsions in the flow profile.

Figure 6a - Comparison of 4 and 32-beams meters response to severe asymmetry (CFD study)

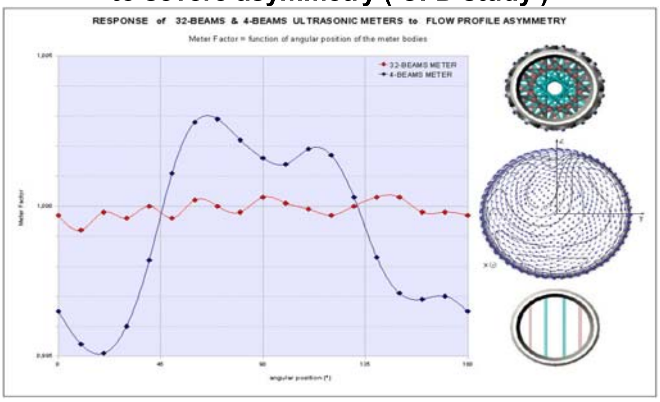
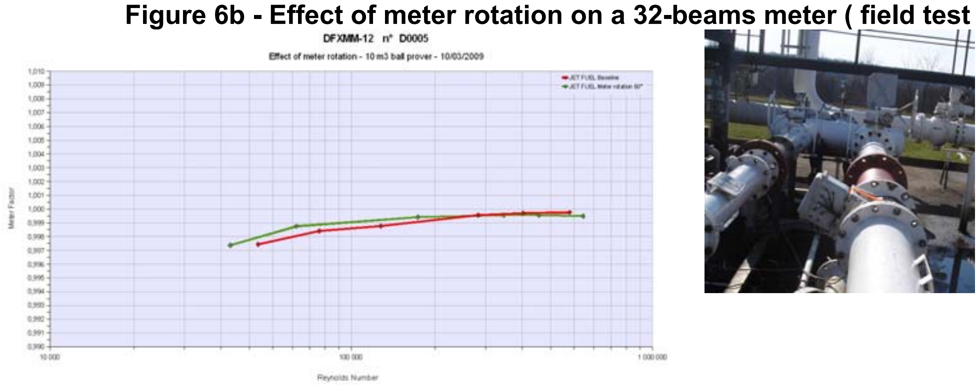


Figure 6b - Effect of meter rotation on a 32-beams meter (field test)



This is a serious advantage where sufficient straight piping is not available, or where flow conditioner is to be avoided - namely offshore -. The advantage is much less evident with normally sized metering runs, where flow profile is (supposed to be) axi-symmetrical.

4.2 Velocity Patterns

The second obvious advantage of more beams is to enable a rich, real-time information on the structure of velocities in the metering section.

Namely, it is possible to record the Velocity Patterns found at calibration time - for each calibration flowrate and viscosity - and to compare them later to what is found on the field.

Figure 7a - Typical Velocity Pattern at calibration time

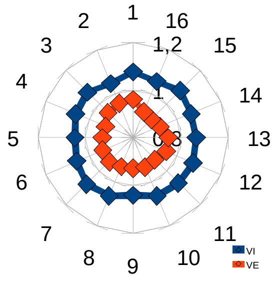
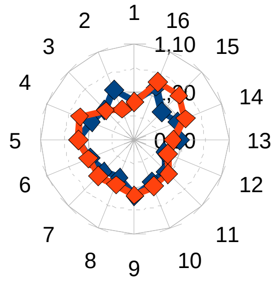


Figure 7b - Typical Pattern difference from laboratory to field.



This approach is in phase with the API recommendation concerning liquid USM :

API MPMS ch5.8 "Ultrasonic Meters" &14 : Diagnostics
" Certain parameters can be monitored based on the specific application. ... Comparing lab determined diagnostic parameters to the same parameters when installed in the field may help identify field installation effects or other parameter changes. It is also recommended to compare these parameters periodically during meter operations."

Let's develop further.

4.3 Case study #1 : 8" meter with different Flow Conditioners.

Yellow boxes :

Meter Factors

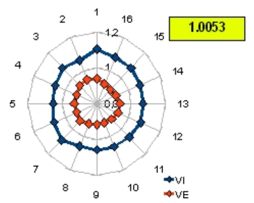
M&T Standard FCS
L = 2D

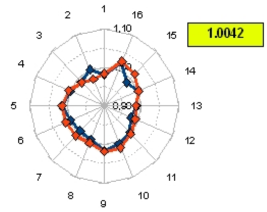
GFC System I
VAS

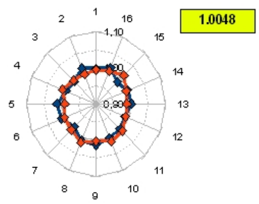
API 19-tubes bundle
L = 4D

REFERENCE FLOW PATTERN | Difference from REF. Scale (+/- 10%) | Difference from REF. Scale (+/- 10%)

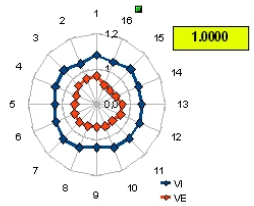
60 m³/h

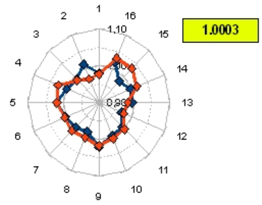


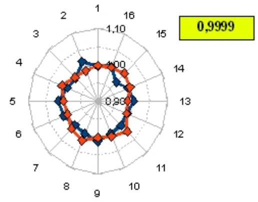




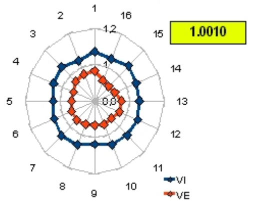
300 m³/h

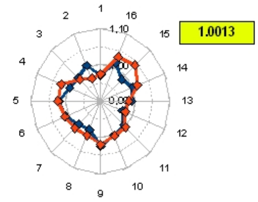


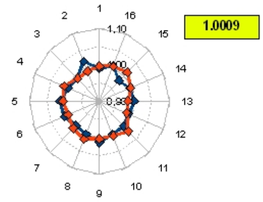




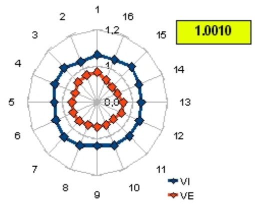
1 000 m³/h

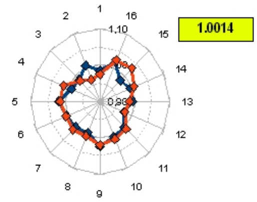


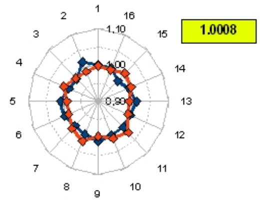




1 500 m³/h



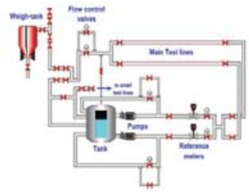
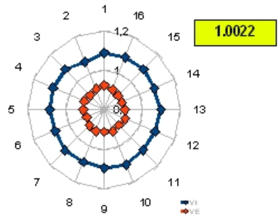
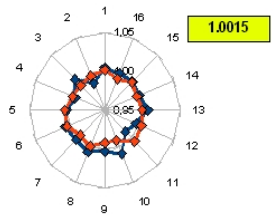
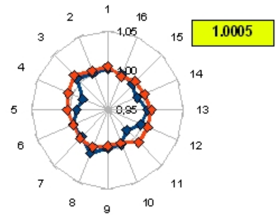
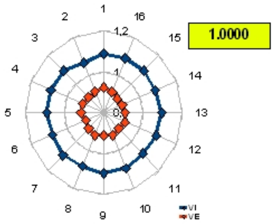
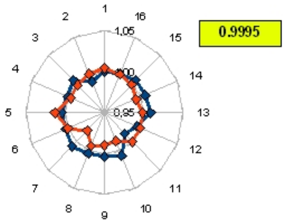
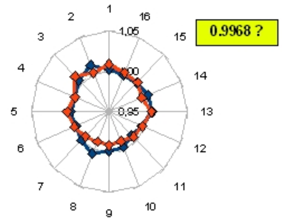
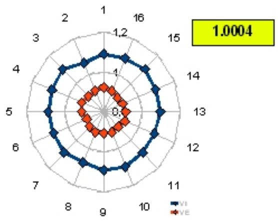
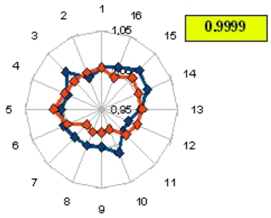
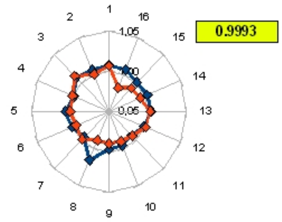
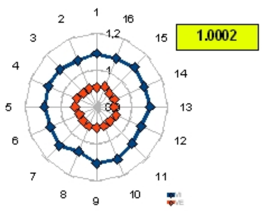
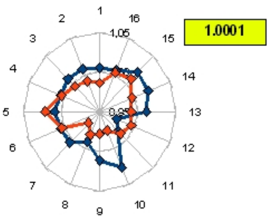
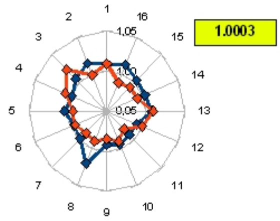




Test conditions :

- *TRAPIL Laboratory, France, July 2009.*
- *8" 32-beams meter, model DFX-MM-08*
- *Diesel oil, 5 cst.*
- *All flow conditionners installed at 15 D upstream (schedule 10)*

5.4 Case study # 2 : 6" meter on different sites and different upstream conditions

	TRAPIL laboratory, FR	**ATYRAU Pumping Station, KZ**	**TUV NEL Oil Loop, UK**
Install :	*15 D schedule 20*	*20 D schedule 40*	*10 D*
FC :	*M&T Standard FCS*	*M&T Standard FCS*	*M&T Standard FCS*
Prover :	*Ball Prover 2.5 m*^{3}	*Compact Prover + master*	*Gravimetric tank*
			
	REFERENCE FLOW PATTERN	Difference from REF. Scale (+/- 5%)	Difference from REF. Scale (+/- 5%)
120 m^3/h			
160 m^3/h			
200 m^3/h			
400 m^3/h			

The striking result of these two case studies is that, despite the significant differences in installation conditions, the Meter Factors found for each flowrate are very similar - within 0.1% -, as soon as the Velocity Patterns are "reasonably close".

A rule of thumb could be that Meter Factors do not differ by more than 0.1% when Velocity Patterns do not differ by more than 2%.

In other words :

SAME INPUTS => SAME OUTPUT

6 CALIBRATION PERFORMANCE MONITORING (CPM)

6.1 Principle of CPM

The basic principle "Same inputs, same output" could look rather trivial.

But, as far as the "input" information is rich - which is the case for a 32-beams meter -, it is possible to take serious operational advantages of it.

Just an example:
"*Same inputs => same output*" means : *No change in pattern => No change in Meter Factor.*

In other words : *no need to prove again or no need to re-calibrate !*

Clearly a way to cut the cost with a better schedule of periodic verifications / recalibrations in the context of a Condition Based Maintenance (CBM) program.
(imagine a 24", 3000 lbs meter located 100 NM offshore ...)

Based on the results above, M&T developed a new method and implemented it as follow :

Figure 8 - The CPM method

CALIBRATION	- Velocity patterns are logged, for each calibration flowrate and viscosity. *Example : 6 calibration flowrates * 3 oils = 18 patterns* - Validated patterns are stored in the meter memory as references.
OPERATIONS	- Current pattern is compared to reference at closest flowrate & viscosity. - Meter software checks for acceptance and manage alarm accordingly. - The comparison/validation process is automatically performed in real-time.

Using procedures based on Calibration Performance Monitoring (CPM) is valuable at all steps of the meter life :

Figure 9 - Calibration Performance Monitoring (CPM) values

CALIBRATION	validate meter installation qualify lab flow profile validate efficiency of flow conditioner	*- detect a protruding gasket, a bad concentricity, ...*
COMMISSIONING	validate skid piping & meter installation	*- same*
PERIODIC CHECK	schedule not only by law, but when needed, under CBM program	*- No change in pattern => no change in Meter Factor*
ANY TIME	reliable "out-of-fiscal-performance" real-time alarm	*- foreign object in the FC* *- abnormal dirt or wax deposit* *- loss of beams due to gas* *- run valve not 100% open*

It is of special value in situations at risk as described in $ 3.3 and Figure 5.

6.2 CPM : practical implementation

The main concerns when Implementing a practical, real-time CPM method are :

- provide quantitative, traceable and auditable data about the Velocity Pattern, so as to make them available to any authority involved,

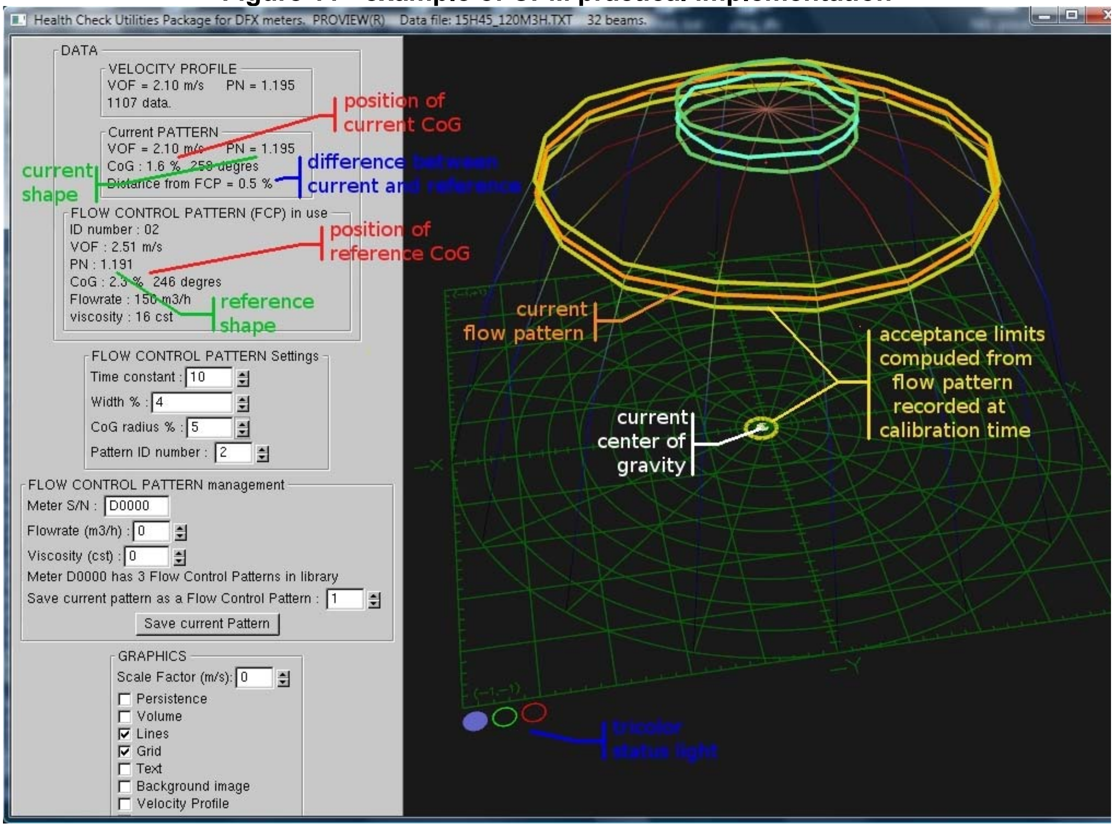
- provide a reliable GO-NOGO (fiscal-nonfiscal) real-time quality indicator, so as to make it available through the supervision to any operator without special metering skills.

6.2.1 CPM data

Figure 10 - CPM real-time quantitative data

Reference 32 Velocities from the calibration laboratory	controls the *quality of lab conditions*
Current 32 Velocities	indicates the "*shape*" of the velocity profile
Position of the CENTER of GRAVITY angle from vertical + position in % of R	controls the *upstream conditions* & the *concentricity of piping*
PROFILE NUMBER ratio BLUE beams / RED beams	*controls the "flatness" of the velocity profile*
SWIRL INDEX	*controls the efficiency of flow conditioner*
" DISTANCE " in % between current and reference patterns	controls the *similarity to lab conditions*

Figure 11 - example of CPM practical implementation



The information is available through the numerical link of the meter.

6.2.2 CPM real-time indicator : Blue, Green, Red

Acceptance limits are defined from the reference Velocity Patterns, both for each individual velocity and for the Center of Gravity of the profile.

The meter then :
- selects the reference pattern at closest flowrate and Profile Number,
- checks if the current pattern match the reference within the defined limits,
- decides for the indicator accordingly.

The information is available as a contact at meter terminals for use by supervision system (logging and alarm).

Figure 12 - the CPM indicator

BLUE	Excellent profile match. Meter probably within +/- 0.10% from calibration.
GREEN	Meter within fiscal accuracy +/- 0.15% from calibration.
RED	Meter out of fiscal accuracy (does not mean out-of-service !)

7 OPEN QUESTIONS / FUTURE WORKS

- Currently running :

- Improve the knowledge of the acceptance limits.

- Extend the database of couples [Velocity Patterns / Meter Factors].

- Medium term :

- Speed up research on the tomographic approach.

7 CONCLUSIONS

1/ As off-site calibration of USMs is more and more considered, securing the transition from calibration laboratory to field is of primary concern.

2/ To achieve this, new control methods and procedures are required, as recommended by API MPMS.

3/ These methods can be successfully implemented on the meters of new generation, thanks to their large number of beams giving a rich and reliable access the velocity profile.

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.