

ISO / CD 17089

Measurement of fluid flow in closed conduits

Ultrasonic meters for gas; meters for fiscal- and allocation measurement.

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1. Introduction

As ultrasonic meters have replaced traditional measurement technologies for the past ten years, the applications have become more demanding. One of the most challenging problems for designers to overcome has been the operation of these meters near large noise sources such as control valves, regulators and -to some extent- also flow conditioners. Being at the forefront of technology both manufacturers and users have taken their part of the problems, but have overcome most of them by sharing their experiences.

Now, after gaining more than ten years of operational experiences with thousands of ultrasonic meters installed under a wide range of operating conditions, the time is ripe for a standard sharing the experiences with all others working in the gas measurement industry.

In contrast to other standards in this area, this (draft) standard is a truly international standard. It is based on the experience and knowledge of experts from all over the world, experts originating from more than 20 different countries.

One of the critical goals was to make this standard open for improvements; something that is especially of importance for a technology where there is still a lot of ongoing research. In order to accomplish this, the standard is written by setting requirements for the performance of ultrasonic meters instead of making demands on the technology.

For a user, in the end what counts is the quality of the measurement under operating conditions and the assurance that the meter will maintain its accuracy. Assuring the quality in the field can only be reached by a chain of controlled actions starting at the manufacturing - through calibration - to the installation and practical use in the field. Therefore requirements have been set, not only for the meter performance at the calibration facility alone, but also for all the other parts involved, including the calibration facilities and the care after the installation in the field.

Following the standard practice, requirements have been set for:

- The performance of the meter at the calibration lab
- The transfer of the quality of the calibration curve to the field
- The conditions during calibration as well as the quality of the lab
- The assurance of the quality of the measurement result in the field
- The operation under field conditions

2. The performance of the meter at the calibration lab and the transfer of the quality of the curve to the field.

A meter calibration curve without the guarantee that the meter behaves the same way in the field is meaningless. Under the almost ideal conditions at a calibration station it is relatively easy, even for a single path ultrasonic meter, to perform well within the accuracy constraints for custody transfer. The only quality needed from the meter is its short time repeatability.

To illustrate this, in figure 1 the calibration certificate of a single path meter is shown. Over the full range, the meter error is within 0.5% and seems therefore suitable for custody transfer applications.

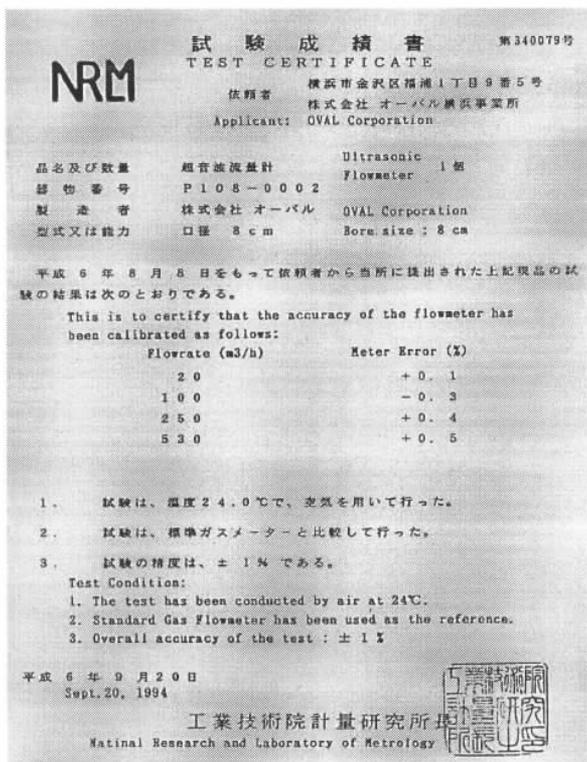


Fig. 1 Calibration certificate of a 3" single path ultrasonic flow meter, based on raw meter data

However in figure 2 the performance of this same meter -after calibration- is shown, when this meter is installed into the field and subjected to all sorts of different pipe configurations. Even with a minimum upstream straight pipe length of 10D, the meter curve may shift 2%; making it unsuitable for a custody transfer applications.

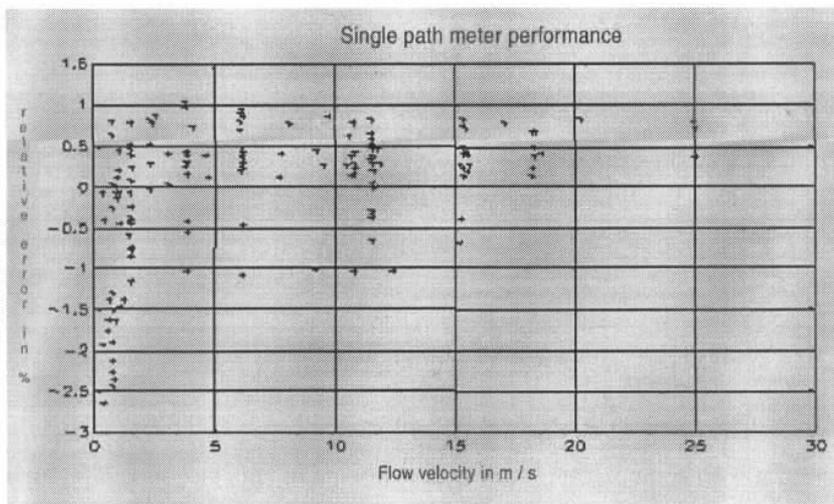


Fig 2. Installation effects on a single path flow meter, including a 10 D upstream straight pipe.

The availability of cheap micro-processors makes things even worse. Especially in the US, there is a trend to apply a multipoint linearization to the meter curve at the calibration site. With that any meter – no matter how badly it is manufactured- will meet the specifications at that moment at that site. However by hiding possible meter defects behind this multipoint linearization, there is absolutely no guarantee that this curve is transferable to the field and it is totally uncertain how much it will shift.

To deal with this, in the standard, special attention is paid to the method on how to judge the performance of an ultrasonic meter and how it can be guaranteed that the quality reached at a

calibration facility can be transferred to the field. For these, the following requirements have been set forward:

- The requirement to judge the quality the meter on the raw and uncorrected curve.
- The requirement to fulfill a series of tests with based on a standardized set of perturbations to guarantee the ability of the meter to cope and operate with real world conditions.

The judgment of the quality of the meter:

Fundamentally, the measurement principle of the ultrasonic meter is linear and its output curve is only influenced by the Reynolds dependent flow profile and the geometry of the meter body; the last one resulting in a linear offset.

Therefore, one of the key requirements set forward in the ISO standard is that the meter shall meet the accuracy requirements prior to making any adjustment other than the standard correction for the Reynolds influence and a linear offset to compensate for the uncertainty in the meter body (ch. 5.8).

Also in order to avoid masking of hidden design defects, in ch. 6.3 it has been stated: “Some manufactures of USM offer linear calibration functions or even arbitrary ones. These functions may not be used to judge the quality of the meter as they might mask hidden design effects. They shall only be applied after approving the meter performance curve.”

The transfer of the quality of the meter to the field:

In order to prove the meter's capability to maintain the quality at calibration in the field a so called “type approval” is presented including tests with the following perturbations representing real-world applications (ch. 6.4):

- *At reference flow conditions*
- *With a single 90°-bend (radius of curvature of 1.5 D)*
 - *USM in normal position*
 - *USM rotated 90°*
- *two 90°-bends in perpendicular planes (radius of curvature of 1.5 D, without spacer between bends)*
 - *USM in normal position*
 - *USM rotated 90°*
- *an expander with a diameter increase of at least one pipe size (typically 2”)*
- *a reducer with a diameter decrease of at least one pipe size (typically 2”)*
- *a diameter step on the upstream flange of the USM with magnitude +3% and –3% (or larger values, if the manufacturer allows for larger steps).*
- *A flow conditioner chosen and positioned by the manufacturer in combination with perturbations above*

For all these situations the minimum upstream straight pipe length must be determined, whereby the influence of the perturbation is less than 0.2%; a value chosen as being identical to the uncertainty of the best calibration laboratories in the world.

3. The conditions during calibration and the quality of the lab.

Automatically, when a meter is taken to a calibration facility, the quality of the facility is assumed to be undisputable. For many facilities like for instance Westerbork, TCC and Pigsar this might be true. However there are other, even official accredited ones for which this is not always the case. As an example in figures 3, the flow during an calibration at an official accredited lab during is shown. In the left figure the 6 calibration points of 200 seconds each are shown in the stepwise curve. The other curve is the speed of sound monitored during calibration. With a constant gas composition and only minor fluctuations in the gas pressure, the speed-of sound can be converted into temperature changes. In the figure on the right side the first 200-second point is expanded. There, the temperature changed during the calibration from +6 °C to 0 °C and back to finally +12 °C.; due to this instability in the line – pack there was a sudden jump in the calibration curve of 0.4%.

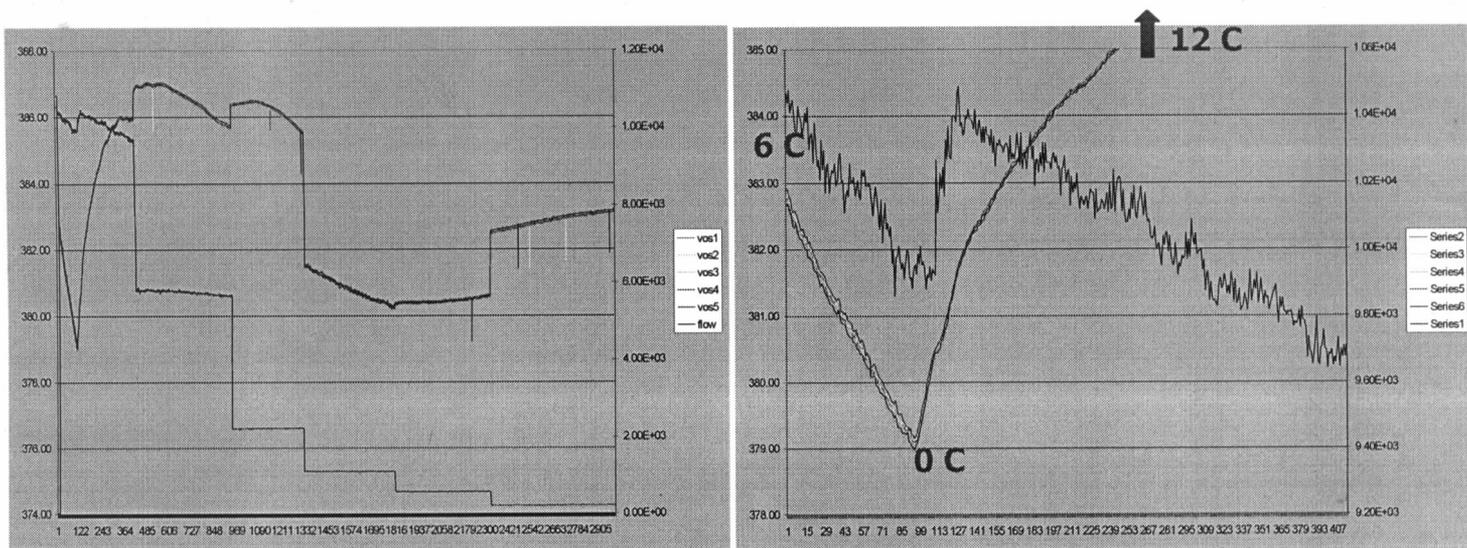


Fig. 3 Instability during calibration; left: the full 6 point calibration – right: point 1 expanded.

Luckily Figure 3 is one of the more extreme examples, but certainly not the only one. Therefore the expert group has decided to set also requirements for the calibration facilities; requirements which have been discussed with and accepted by most of the leading facilities. In ch. 6.3 it has been stated that:

Any measurement shall be rejected when either of the following conditions is encountered:

1. $\Delta_{LP} > 0,2\%$ per measurement (line pack)
2. $\Delta T > 0,25K$ per 100s (temperature drift)
3. $\Delta P > 0,2\% \cdot P$ per 100s (pressure drift)
4. $\Delta Q > 3\% \cdot Q$ per 100s (flow rate drift)
5. Pulsations inside the calibration facility shall inflict no larger error than 0.05% on the reading of the reference meter(s) and the meter(s) under test.

4. Maintaining and assuring the quality of the measurement result in the field.

To ensure that the USM, once in service, will continue to meet the expected performance requirements after its installation, an audit trail must be set-up using the data taken at the calibration facility, where the uncertainty has been set to the lowest attainable level, as the reference point.

In contrast to many other meters, USM's can deliver extended diagnostic information through which it may be possible not only to verify the functionality of an ultrasonic gas flow meter, but also several other components within the system, such as the gas chromatograph and the pressure and temperature transmitters. Due to the extended diagnostic capabilities, the ISO standard advocates the addition and use of automated diagnostics instead of labor-intensive quality checks.

The Speed-of-Sound (SOS) is one of the key diagnostic factors and can be used both in:

- an absolute way, comparing the measured value with the calculated one based on the gas composition, pressure and temperature.
- a relative way, comparing the "SOS footprint" taken at the calibration lab with the one obtained in the field.

In case an *absolute* comparison, the differences between the measured SOS and the calculated SOS may indicate:

1. Asynchronous determination of measured SOS and the calculated SOS due to fluctuations in gas composition and analysis time lag.
2. Malfunctioning of :
 - (1) USM
 - (2) Pressure measurement
 - (3) Temperature measurement
 - (4) Gas composition measurement
3. Depositions on the transducer(s) and/or meter body which changes the path length.

Relative comparisons can be made with ultrasonic meters having 3 or more paths. The advantages of this method are:

- It is independent of the gas composition.
- The measurement can be performed under flowing conditions; at high velocities acoustic path length may change --thereby increasing the discrepancy.
- The calculation can be automatically done as part of a diagnostic package

The comparison may be displayed graphically as a "footprint". As an example, in figure 4 the footprint is shown from a 5-path ultrasonic gas flow meter, showing the ratios measured at the dry calibration and wet calibration. In these figures all the different ratios of the Speed-of-Sound from the various paths are shown. The ratios are numbered according to the path numbers; 5/1 means the Speed-of-Sound from path 5 divided by that of path 1 etc.

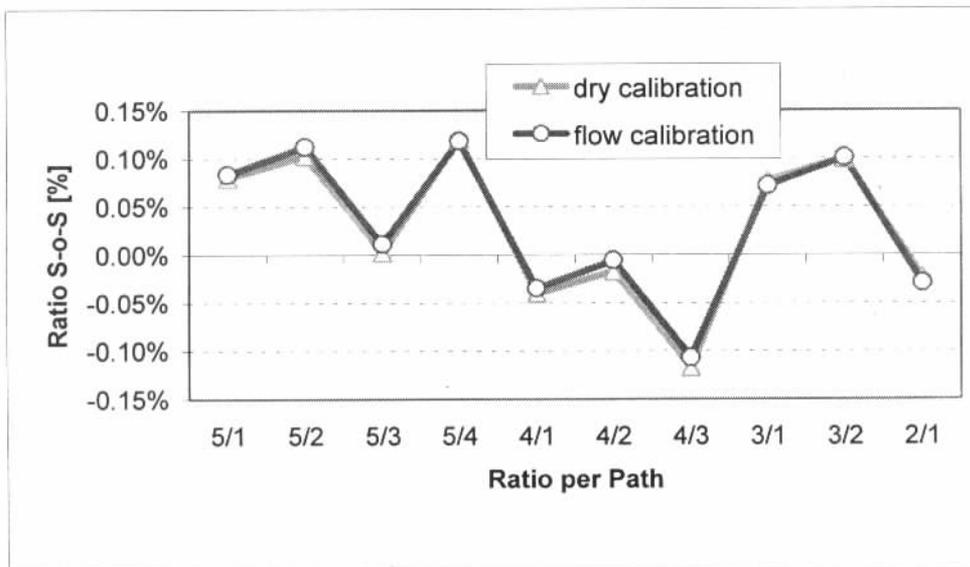


Figure 4 — Footprint: Ratio pattern determined during dry calibration with nitrogen and life during the flow calibration at the calibration facility

This is just an example and it must be noted that different graphs may be generated, dependent on the meter configuration, to serve as a footprint.

A change in the shape of the footprint over time may indicate malfunction of a path of the USM with a resulting potential for miss-measurement. Footprints from FAT, dry calibration, flow calibration and the field may be compared in order to monitor changes in the behavior of the USM.

Although the Speed-of-Sound (SOS) is one of the most important parameters to be used in verification, other parameters may be monitored in order to ensure optimum performance; examples of these parameters are:

- Velocity Ratios; monitoring on basis of historic relationship of meters' individual path velocities
- Profile Factor Number; monitoring on basis of historic profile factor number
- Automatic gain control
- Etc.

Another method is the Inter-comparison checks between multiple meters in series. With two USM's operating in series, a systematic approach may be employed to monitor the quality of the meters (with exception of common mode errors). This systematic approach is called the "flow reference meter method" (FRMM); a method employed by Norsk Hydro for their off-shore installations.

The systematic approach of the FRMM comprises a number of steps of which the first step is:

"Establish and maintain the Historic Difference Footprint (HDF), the difference between hourly volume totals at line conditions for various flow rates within working range, beginning at the first start-up. Establish a Monthly Difference Footprints (MDF) at regular intervals during operation. Only hours containing stable flow conditions may be included. Hours containing start-up, shutdown, wet gas or other instabilities may be disregarded."

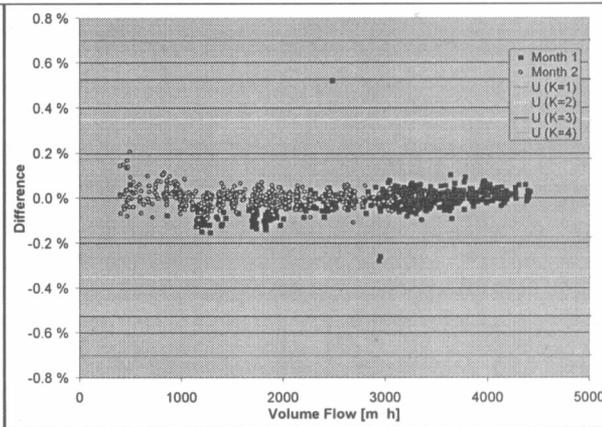
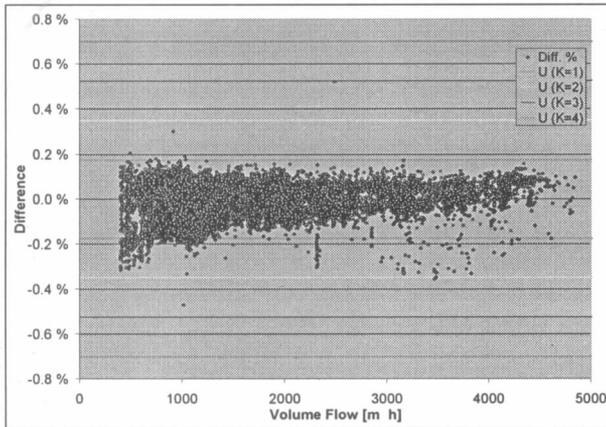


Fig. 5 Historic Difference Footprint (HDF)

Fig. 6 Monthly Difference Footprints (MDF)

Useful histograms are the Historic and Monthly Difference Histograms (HDH and MDH), see Figures 5 and 6.

After that the control limits for the change (Δ) of the MDF and HDF are determined, based on the uncertainty envelope of the ultrasonic meter. Dependent on the meter performance in respect to the control limits, actions are taken (a full overview is presented in ch. 7.5)

5. The operation under field conditions; installation at an M&R station.

Aside from the metrology requirements as described above, the 60+ pages of the ISO 17089 are filled with all kinds of useful information and guidelines. One of the most practical and unique parts is that describing the application of an ultrasonic meter at an M&R station. Here regulating valves can create so much noise that a measurement is not possible any more.

Pressure regulating valves are producing noise not only within the audible- but also in the ultrasonic range. The amount of noise depends on the process conditions, such as pressure and flow. When a control valve (pressure regulating valve) is installed in the vicinity of an Ultrasonic Flow Meter, the acoustic noise levels emitted can interfere with the acoustic signal and the loss of flow measurement is eminent. The emission and the spectral distribution of the noise are valve and trim dependent.

The standard presents a calculation method through which a prediction of the performance of an ultrasonic meter at a M&R station can be made and whether a measurement is possible or not. For this, the following items have to be investigated:

- The generation of the noise by the control valve as a function of the operating envelope of the M&R station.
- The propagation of noise from the valve to the USM (N_d)
- The signal strength of the USM (p_s)

The outcome of this is the signal to noise ratio at the USM. Together with the minimum required S/N ratio (Δ critical) of a meter, a prediction on the performance of the meter can be made.

Here there is a shared responsibility for:

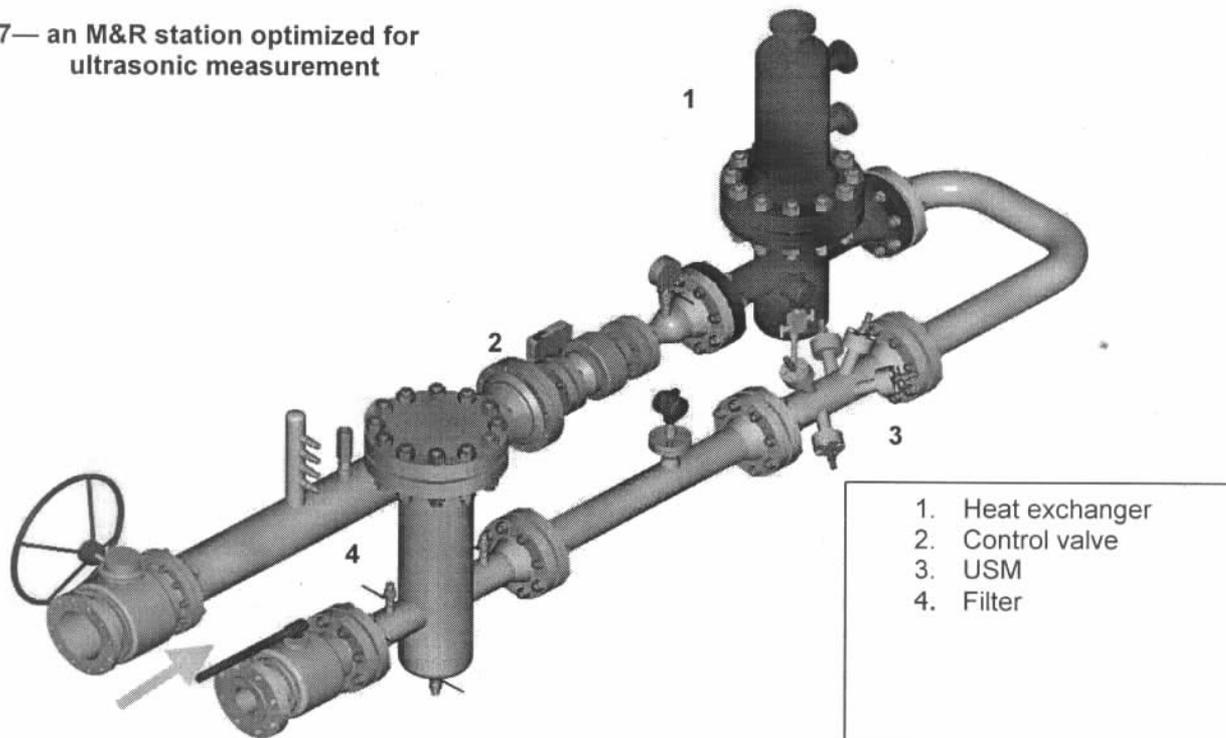
- the operator who determines the operating envelope
- the valve manufacturer who designed the valve that is the source of all the noise
- the manufacturer of the ultrasonic flow meter

Installation at a M&R station.

To provide an optimal solution, the noise issue needs to be addressed in the early design stage of an M&R station. In contrast to the design of a turbine meter station, where the turbine meter is normally positioned downstream of the regulating valve, for an ultrasonic meter station the ultrasonic meter must be placed upstream the regulating valve and even before the heat exchanger (see figure 7). The obvious advantages of this set-up are:

- The ultrasonic meter is placed in the high-pressure area that improves the ultrasonic signal strength.
- The heat exchanger is placed between the noise generating valve, acting as a silencer (in many cases a heat exchanger attenuates more than 20 dB)
- In most cases the noise created at the upstream side is 3 to 6 dB lower than for the downstream side .

Figure 7— an M&R station optimized for ultrasonic measurement



Next to this, the ISO 17089 contains many practical guidelines for the installation and use of ultrasonic flow meters in the field. It does not only address full-bore meters but is also applicable for reduced bore meters and it contains the equations for the correction for the influence of pressure and temperature. The ISO 17089 is structured as follows:

The structure of the ISO 17089

Foreword

1. SCOPE

2. NORMATIVE REFERENCES

3. DEFINITIONS AND SYMBOLS

4. PRINCIPLES OF MEASUREMENT

- Explain the principles of measurement
- Commonly used multipath cross-sectional configurations
- Estimation of uncertainty in measurement
- USM Classification
- Method for the calculation of the expansion of the meter body due to pressure or temperature changes

Example: analysis for a pressure difference of 30 bar (440 PSI) and a temperature difference of 15 °C (27 °F).

5. METER CHARACTERISTICS

- Operating conditions and the USM
- The specification of path configuration and transducer arrangement
- The standard includes reduced bore meters. The improvement of the flow profile by bore reduction is well known phenomenon. However critical is that the angle of chamfering does not exceed 6 degrees, guaranteeing no separation of the boundary layer
- The position and the construction of temperature and density measurement
- Accuracy requirements for Class 1 and Class 2 meters in terms of Repeatability, Reproducibility, Resolution, Zero flow reading, Maximum Permissible Error and Linearity
- Requirements for the operating- and installation conditions as well as the performance of the USM under these.
 - Sound / noise / pressure regulating valves
 - Contamination
 - Non-steady flow
 - Installation requirements and flow profile considerations
 - Protrusions / diameter step
 - diameter steps between the upstream pipe and the meter can cause metering errors in the order of 0.05% per 1% diameter step; an error that can be reduced by chamfering. Therefore the maximum diameter step within 10D upstream of the meter is 3%.
 - Thermo wells / density cells
 - Flow Conditioners
 - Internal Surface / wall roughness
 - Bi-directional use

6. TEST AND CALIBRATION

- Dry calibration
- Laboratory flow calibration

- duration of the calibration for the purpose of accuracy
- the uncertainty of the test facility
- the stability of flow, pressure and temperature and on the calculation of line pack.

6. Δ_{LP} > 0,2% per measurement (line pack)
7. ΔT > 0,25K per 100s (temperature drift)
8. ΔP > 0,2% · P per 100s (pressure drift)
9. ΔQ > 3% · Q per 100s (flow rate drift)

- Conditions for a limited calibration range
- Bi-directional calibration
- Calculation of Flow Weighted Mean Error (FWME)
- Calibration factors:
 - o Some manufactures of USM offer linear calibration functions or even arbitrary ones. These functions may not be used to judge the quality of the meter as they might mask hidden design effects. They shall only be applied after approving the meter performance curve.
- o Type testing
 - o Demands the determination of the L_{min} of the calibration facility
 - o Installation conditions

7. AUDIT TRAIL AND OPERATIONAL PRACTICE

- o Required documentation to set up an audit trail
- o The use of diagnostics when in operation
- o Speed of sound (SOS)
 - o Absolute SOS comparison
 - o Relative SOS comparison; footprint
- Other parameters
 - Velocity Ratios; monitoring on basis of historic relationship of meters' individual path velocities
 - Profile Factor Number; monitoring on basis of historic profile factor number
 - Inter-comparison checks between multiple meters in series
- o recalibration

8. SPECIAL APPLICATION NOTES

- VALVE CHARACTERISATION AND NOISE (in a metering & regulating station)

Interaction between the meter run/station designers – manufacturers. Stating the responsibilities of the parties involved.

The calculation method.

- o the generation of the noise by the control valve:
- o The propagation of the noise from the valve to the USM (N_d)
- o The signal strength of the USM (p_s)
- o The signal to noise ratio at the USM
- o Optimal M&R station design

- Electronics design testing

Conclusion

During the three years of its existence in its present setting, the ISO TC 30 / SC 5/ WG1 on ultrasonic meters for gas has worked hard to create a truly international standard that is aimed at the practical use of ultrasonic flow meters. It sets requirements for the manufacturers and gives guidelines to the users to ensure the highest quality of measurement at a level of assurance that at this moment only can be obtained with ultrasonic meters.

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