An overview of natural gas metering with ultrasonic technology including "On-line" (or "Live") meter validation

by **Achim Zajc**

Introductory concepts for the measurement of natural gas using the principle of pulse transit time measurement are discussed in this white paper. Diagnostics typical to multipath transit time meters using ultrasonic pulses are also described, along with multipath arrangements and transducer types. Guidance is provided for the proper application, installation and condition-based monitoring of ultrasonic meters with respect to RMG by Honeywell technology to assure continued measurement integrity.

1. INTRODUCTION

Over the past 20 years, gas ultrasonic meters have transitioned from the engineering lab to wide commercial usage as the primary device-of-choice to measure gas volume for fiscal accounting. Acceptance by gas pipeline companies has occurred during this time due to the device's:

- Reliability.
- Accuracy.
- Repeatability.
- Capacity.
- Rangeability.
- Low maintenance.
- Adoption of industry standards for fiscal measurement applications.

Briefly, the historical development of fluid velocity measurement in closed conduits with sonic pulses was first considered in the 1920s with the discovery that transmission and reception of repetitive sound bursts could be used to describe the location and speed of moving objects; this principle was soon used to build sonar and radar arrays. Attempts were made over the years to apply this principle to measurement of fluid velocity in conduits, but it wasn't until the development of economical high-speed electronics and digital signal processing in the late 1970s that a repeatable instrument with sufficient resolution for gas applications was devised.

Over the following decade and a half, the practical challenges of making the technology commercially viable as a flow measurement device were described and addressed through innovation and development that resulted in the production of a gas ultrasonic meter that utilizes:

- Robust transducers generating repeatable pulses (amplitude and frequency).
- Multiple paths to average axial velocity components over the cross-section of a closed conduit (i. e., pipe).
- High-speed electronics complete with an accurate clock to detect, resolve and time transmission / reception of sonic pulses with sufficient time domain resolution.
- Integrated transducer and electronics to permit high pulse transmission rates. Their transit time measurement allows rapid integration of fluid flow velocity so accurately measured values can be reported once per second.

Virtually all ultrasonic meters used for fiscal measurement are flow calibrated at meteorologically traceable test labs. Flow tests are conducted at multiple points over the meter's operating range to characterize its proof curve. Meter factor(s) are then calculated and applied to correct the meter's output to the lab's reference standards.

An advantage of modern ultrasonic meters is that once a meter is flow calibrated, diagnostic assessments can describe

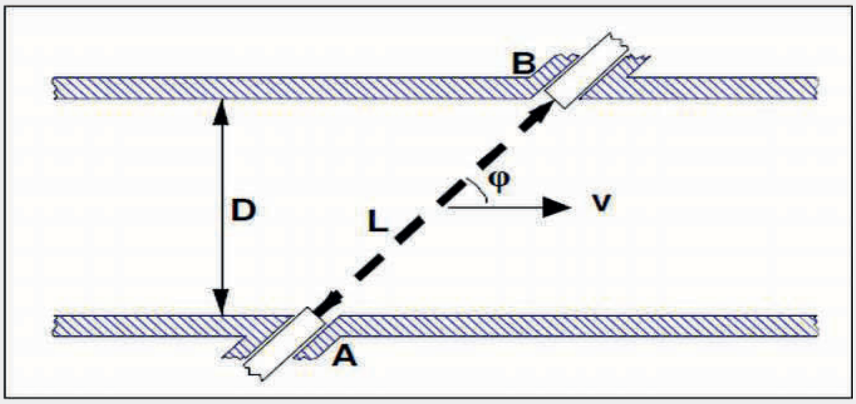


Figure 1. Principal schematic of a transit time ultrasonic meter

proof (i.e., meter factor shifts due to a fault in the meter's operating elements, such as transducers and/or processing electronics) so that re-calibration generally isn't required (although some regulatory authorities mandate re-certification at set intervals, these mandates vary by jurisdiction).

2. OPERATING PRINCIPLE

Knowledge regarding the measurement principle of ultrasonic meters lays a foundation for optimal field application as well as providing the basis for understanding whether the meter continues to accurately and reliably measure gas volume.

Multi-path ultrasonic meters are typically used for gas custody transfer to calculate gas flow rate from velocity measurements made over a pipe's cross-section. This is accomplished using the following process:

- Transducer pairs are installed in a meter body and used to make transit time measurements of ultrasonic pulses, which each transducer transmits and receives. Pulses shot in the downstream direction are accelerated, while those shot upstream are decelerated by the gas flow. (At zero flow, transit times in the up and downstream directions are equal.).
- Velocities are calculated for each transducer pair, or path, from the measured transit time difference between pulses shot in the up- and down-stream directions.
- Multiple path velocities are averaged into the bulk velocity using a weighting scheme that depends on the path's location in the pipe cross-section for which velocity is "sampled".
- Bulk velocity is multiplied by the meter body's cross-sectional area to calculate uncorrected flow rate.

Velocity measurements are made along multiple paths using transducer pairs arrayed in a known position in the meter body. Since the "absolute digital travel time measurement method" is employed (firing pulses in rapid succession in opposite directions across the same flight path in the pipe), fluctuations in pressure, temperature and gas composition do not affect velocity measurement due to the nearly instantaneous sonic pulse emissions by individual transducer pairs.

Below are the basic equations [1,2] used for transit time measurement (Equation 1, 2), bulk velocity (Equation 3), speed of sound (Equation 4), flow calculation (Equation 5) and a schematic (**Figure 1**) of a transducer pair's geometry that puts the vector sums into context. Note that the only thermodynamic term in any of these equations is c, the speed of sound. This is a fluid property, and the only term in these equations that varies with gas composition, pressure and temperature (i.e., fluid density).

$$t_U = \frac{L}{c - v \bullet \cos\varphi} \qquad \text{(Equation 1)}$$

$$t_D = \frac{L}{c + v \bullet \cos\varphi} \qquad \text{(Equation 2)}$$

$$v = \frac{L}{2 \bullet \cos\varphi}\left(\frac{1}{t_D} - \frac{1}{t_U}\right) \qquad \text{(Equation 3)}$$

$$c = \frac{L}{2} \bullet \frac{(t_u + t_d)}{t_u \bullet t_d} \qquad \text{(Equation 4)}$$

$$Q = A \bullet V \qquad \text{(Equation 5)}$$

Where:

L = Path length (ft or m)

t_U = Transit time upstream (sec)

t_D = Transit time downstream (sec)

c = Speed of Sound (fps or m/s)

φ = Path angle (degrees)

v = Path velocity (fps or m/s)

Solving for velocity, v, in equations 1 and 2, and combining their terms, results in the solution of interest: fluid velocity v (Equation 3). Note that the density-dependent term, c (speed of sound) cancels and drops out of equation 3. This is possible because fluid density (i.e., composition, pressure and temperature) is assumed to be constant at the time when the up- and downstream pulses are fired (a reliable assumption given that up- and downstream pulses are fired within milliseconds of one another). The mutual effect, and therefore cancellation of c on the up/down pulses, gives rise to the description of the meter's operating principle as the "absolute digital transit time measurement method."

Application of the absolute digital transit time method provides the technique needed to render accurate gas measurement, and its integrity is dependent on:

- Knowledge of path length (distance traversed by ultrasonic pulses).
- Confirmation of clock accuracy (accurate transit time measurement).
- Validation of pipe cros s s ectional area (accuracy in flow calculation, and transit time measurement).
- Validation of flow profile (accuracy of calculation of bulk velocity from individual path velocity measurements).

Diagnostic outputs monitored must verify the constancy of the bolded items in these bullets, in whole or part, to provide an assessment of the meter's operating condition.

3. APPLICATION CONSIDERATIONS

All gas measurement technologies, including ultrasonic meters, have limitations. It is important for engineers and technicians that use any flow measurement technology to consider the limitations of the primary device proposed for use at a particular meter station prior to installation. Careful consideration before construction and installation can avoid costly re-work should the chosen technology prove less than optimal for the particular measuring station's operating scenario.

3.1 Noise

As noted in the operating principle discussion, ultrasonic flow measurement depends on accurate transit time measurement of sonic pulses. Sound is characterized by its tone (frequency) and loudness (amplitude). In the case of an ultrasonic meter, the tone or frequency of the pulses is above the range of human hearing (20 kHz), hence the modifier "ultra."

Noise inside the pipe work can interfere with detection of sonic pulses if it is of coincident frequency with the meter's transducers, and "drowns out" the pulse if it is sufficiently high in amplitude. If pulses are drowned out, detection, and therefore pulse transit time measurement, become impossible and flow measurement stops.

Designers should always be concerned with the possibility of noise interfering with an ultrasonic meter's function, and should avoid installation near a noise source. That's easy (and obvious) to state, but in practice hard to accomplish since the most common noise sources are flow and pressure control valves, which are almost always co-located with meters at gas transfer stations. It is also notable that the noise offensive to an ultrasonic meter is inaudible to human hearing, so the valve sets that commonly cause interference are quiet or "whisper" trim style valves. These valves achieve their inaudible noise characteristic with trim designs that push the noise out of the range of human hearing, but into the ultrasonic range where UMs operate.

Therefore, designers should install ultrasonic meters where they will be least affected by the noise generated by such valves. Most UM manufacturers can provide additional guidance particular to their product. In general:

- Meter ins tallation: Install ultrasonic metering upstream of regulating devices.
- Nois e reducers: Locate noise attenuating elements between the meter and the noise source (e.g., tees, separators, etc.).
- Cons ult the meter manufacturer: They may have transducers of alternate frequency less susceptible to noise interference and/or the knowledge-base with respect to their meter's response. This way a proposed installation can be analyzed for possible impact based on the valve type, flow and pressure drop, followed by a recommendation for attenuators that militate against possible interference.

3.2 Dirt

Dirt and liquids can impact the performance and accuracy of ultrasonic meters, as they do all other flow measurement technologies. The effects vary depending upon the nature of the technology. For example, dirt gathering on the interior of an orifice tube or plate will have impact on the dimensional characteristics upon which orifice meters rely. In the case of turbine meters, it may cause the meter to run slow due to an increased bearing friction. In ultrasonic meters, it concerns exits with respect to transducer blockage and dimensional integrity (diametral and path length changes).

In terms of diametral changes, recall that in an ultrasonic meter, velocity is measured and uncorrected flow is calculated from the product of cross sectional area and the measured velocity. A percent change in area equates to a percent change in calculated flow. Therefore, there is a 1 : 1 relationship between diameter error and measurement error. Path length changes due to trash build-up on transducer faces also cause measurement errors, but these dirt-induced errors are easily detected using speed of sound comparisons (see Diagnostics below).

Dirt build-up in the meter causes larger measurement errors, but is harder to detect than a dirt-induced path length change. Subtle diagnostic indicators can be monitored, but regardless of the suspicion these indicators might flag, it is usually necessary to make a visual inspection and then clean the meter internals to eliminate the diametral reduction. Operators should:

- Make meter installations with a site assessment of the possibility for liquids / dirt contamination in mind and consider the addition of inlet separators, filters and drains on the meter run to either prevent contamination from occurring, or to provide a mechanism to drain liquids from the meter run.
- Consider installing the meter run with a mild slope to discourage accumulation of liquids down the length of the meter run and through the measuring section. Liquids will tend to accumulate at the lower end of the meter run, which would also be the ideal location for a drain.
- Install inspection ports or even tees with uni-bolt closures to allow for visual inspection with a bore-scope and, in the case of inspection tees / caps, to permit for meter run cleaning.
- Adopt a regular program of diagnostic and visual inspection to detect build-up and avoid measurement errors due to diametral reduction.

3.3 Profile Distortion

As noted in the operating principle discussion, resolution of path velocities into a representative bulk, or average, fluid velocity, is essential to accurate calculation of uncorrected flow at line conditions. As such, it is necessary to ensure the flow profile is consistent with that found during flow calibration and, additionally, that the profile is symmetrical (**Figure 2**) in shape so that the individual path weighting factors applied by the meter manufacturer retain their validity.

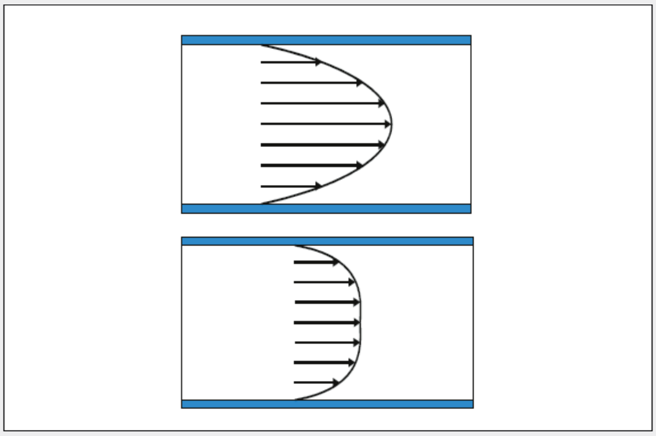


Figure 2. Laminar and turbulent flow profiles

Therefore, path velocities should be mapped during flow calibration and subsequent field inspections should compare the asfound flow profile to that documented when the meter factor was established during calibration in the flow lab. Meter manufacturers usually employ different path configurations from one another in the quest to characterize the flow profile and accurately calculate bulk velocity; some designs are more effective in this regard than others, although arguments can be made that high-performance flow conditioners, designed to generate consistent flow profiles, render this distinction moot. Regardless of whether or not a flow conditioner is used, it is still critical that a multi-path meter provide indication when the asfound profile deviates from that expected (i.e., from flow calibration). A good meter's path design will enable calculation and reporting of swirl and asymmetry.

Profile distortions can occur due to meter run obstructions, debris accumulation or surface roughness changes on the pipe wall, as well as protrusions installed upstream of the meter (e.g., sampling probes or thermo-wells). However, the most common source of profile disturbance is standard pipe work such as tees, elbows and headers. These elements generate swirl, asymmetry or a combination of the two (**Figure 3**).

General practices to ensure a consistent flow profile include:

- Design meter runs that minimize profile distortions (long runs of straight pipe of the meter), or include elements such as flow conditioners, that normalize them. (Note: if user select to use flow conditioners, the meter must be calibrated with the flow conditioner installed in the same position in the meter run, relative to the meter, at both the flow lab and field installations.).

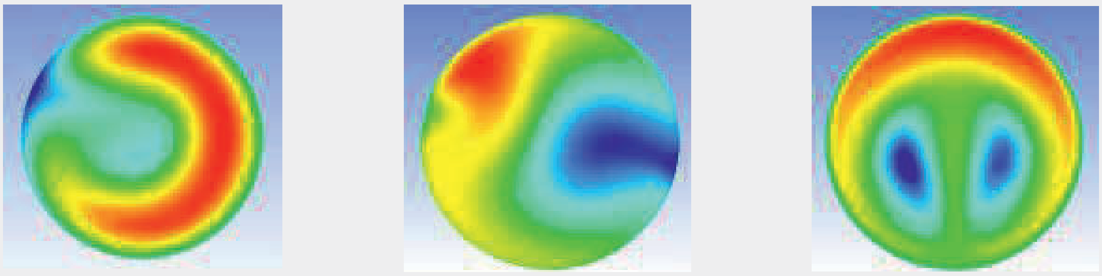


Figure 3. End view representations of swirl, asymmetry and cross flow

- Select a meter design employing a multi-path design that properly characterizes the flow profile and can report via its diagnostics whether swirl and / or asymmetry are present.
- Upon initial meter start-up, map the flow profile once again to verify that the translation of the flow calibrated meter system (meter run, meter and flow conditioner if used) to the field is valid; if the profile in the field is different than that measured at the lab, there is a shift in meter factor!

An area of continuing manufacturer research is development of paths designs that permit repeatable disturbance descriptions and measure their coincidental impact on meter factor shifts. With this design and information on meter factor shift, it will then be possible to correct meter output for the disturbance. This is a steep challenge since the degree and type of disturbances varies, and characterizing meter response to these many influences demands a large and statistically reliable body of accurate data.

3.4 Installation Requirements

As discussed in the previous chapters, for a correct measurement it is very important that the flow profile isstable and repeitable. Typical upstream piping elements such as bends, headers, T-joints, flow conditioners, filtration equipment, diameter changes (steps, expanders or reducers) and valves will create swirl and asymmetry to the flow profile. As described in ISO 17089 – 1 [2], asymmetric profiles may require an inlet spool of 50 DN without a flow conditioner, and swirl may require 200 DN straight pipe without a flow conditioner before a fully developed flow profile can be assumed.

Obviously, 50 DN or 200 DN straight inlet pipes are not suitable for a standard meter run installation, but the ISO Standard 17089 – 1(2) and AGA Report No. 9 apply different solutions to making shorter meter runs for custody use. ISO 17089 – 1 [2] recommends a straight inlet pipe between 30 DN and 50 DN without flow conditioner and an outlet spool of 3 DN as a minimum. With the flow conditioner, the recommendation is to have 10 DN straight pipe between the flow conditioner and the ultrasonic meter.

This contrasts to what the AGA 9 Report suggests as a default configuration of a [1]. flow conditioner should be placed between two 10 DN straight pipes, the latter pipe leading towards the ultrasonic meter and then followed by a 5 DN straight outlet spool. Most North American users employ a 5 D, flow conditioner and 10 D spool upstream of the meter inlet, and 5 D downstream. Some users prefer honed upstream sections to millitate against dirt build-up, but this adds to cost.

Unfortunately, ISO 17089 – 1 and the AGA 9 Report do not clearly state installation conditions or requirements for uni- and bidirectional operation. And what is stated is in contrast to each other and may cause confusion and even prevent more sophisticated technology with the need for smaller straight inlet spools to be used. Many end users follow Standards and Reports to be on the safe side, but could end up losing money (higher investment) and space if they are not following new technology trends.

Different approaches between AGA and ISO also exist for the allowable protrusions (for e.g., thermowells) and diameter steps [1, 2]. Both ISO 17089 – 1 and the AGA 9 Report state that the inlet and outlet spools should be straight and have the same diameter as the ultrasonic meter. The AGA 9 Report says the inner diameter of the inlet and the meter have to be within 1 % of each other. ISO 17089 – 1 states within 1 % as preferable, but within 3 % as maximum.

Figure 4 shows the installation requirements of the USZ 08 from RMG by Honeywell for unidirectional operation. **Figure 5** shows the installation requirements of the USZ 08 from RMG by Honeywell for bidirectional operation. Both installation requirements align with the type approvals for custody transfer measurements according PTB and MID [3, 4]. It is recognized that flow conditioners are typically used in the Americas at 10 D upstream of the meter and the RMG by Honeywell meter performs beyond the limits of AGA 9.

First, the inlet spool requirements are significantly smaller than the ISO and AGA Guidelines requested (10 DN without flow conditioner and 5 DN with flow conditioner) for both operation modes and this is confirmed in the type approval certificate (although the flow perturbation tests due to MID, TRG 13 and OIML 137 – 1 are fulfilled by the USZ 08 with these much shorter inlet spools) [5, 6 and 7]. This helps to reduce investment expenses and costs for a much smaller installation.

Secondly, the diameter set up is allowed to vary from – 2 % to + 5 % (7 %) and the ultrasonic meter still measures the requested accuracy in the ISO Standard and AGA 9 Report. This is much less strict than the AGA Report or the ISO Standard and provides a great deal of installation flexibility. This test has been done on third-party-approved test rigs and the results are documented in the type approval for custody transfer measurement [3, 4].

For the installation of temperature measurement, both the ISO Standard and AGA 9 Report suggest the installation of 2 DN to 5 DN downstream of the ultrasonic meter for unidirectional operation. For bidirectional use the temperature measurement should be installed from the ultrasonic meter flange 3 DN to max 5 DN. In general, the temperature measurement has to be installed in such a way that it is representing the gas temperature and is not affected by the ambient temperature.

4. DESIGN CHOICES

4.1 In General

In the development of gas ultrasonic meters, manufacturers necessarily make design choices that balance the desire to build the "perfect" meter with the need to provide an affordable solution that meets customer needs and existing measurement standards (e.g., AGA TMC Report No. 9 [1] and ISO 17089 [2]).

Although the absolute digital pulse transit time method is a measuring principle common to all ultrasonic meter manufacturers, the design choices they've made for their products set each apart:

- Transducer design.
- Path orientation / geometry.
- Number of paths.
- Pulse detection algorithms.

4.1.1 Number of Paths

From the previous discussion of profile distortion and the need for profile repeatability, it is evident that the more samples of the velocity stream (that is, more paths in a meter), the better the measurement. However, it's also obvious that more paths means higher cost and results in the Signal Processing Unit (SPU) having to digest more data, which might slow down volume output reporting because of a higher calculation overhead. Additionally, in smaller meter sizes, it is not possible to install a large number of transducers due to physical limits on available space.

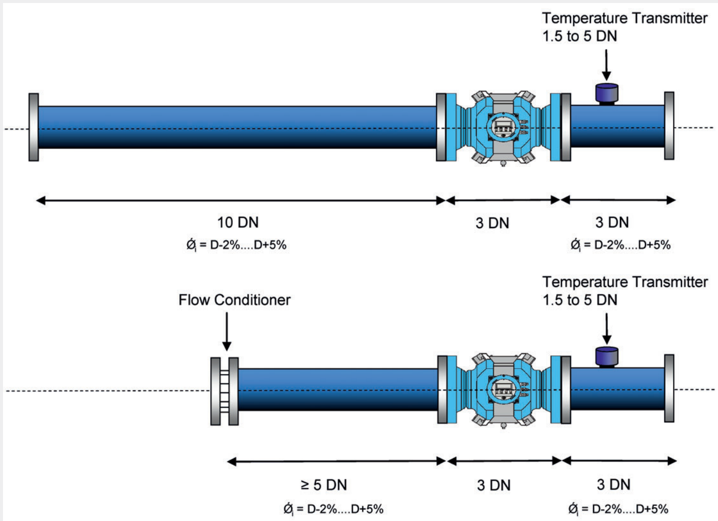


Figure 4. Typical installation requirements for a unidirectional operation

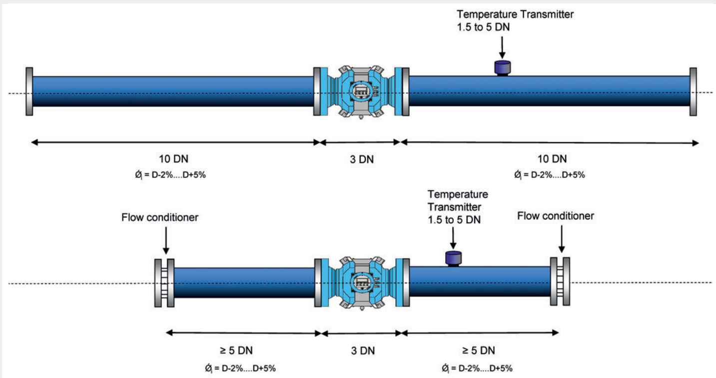


Figure 5. Typical installation requirements for a bidirectional operation

4.1.2 Path Orientation

Limits on the number of paths and a desire to maximize sampling/characterizing of the flow profile can be stretched (if not overcome) with careful positioning, or orienting, of the transducer paths. Once again, there are trade-offs between getting more slices of the measuring section's cross section versus axial orientation that can measure swirl, cross-flow and asymmetry. Some manufacturers use a path orientation that bounces ultrasonic signals off pipe walls to increase axial sampling, while others use point-to-point transmission to avoid pulse attenuation and warping that can compromise signal detection.

4.1.3 Transducer Design

Ultrasonic transducers are engineered to deliver maximum amplitude at given frequencies while maintaining transmission of a uniform pulse shape that is repeatable so the pulse can be reliably detected. This is a challenge that's been answered in various ways, once again involving trade-offs between benefits, cost and reliability. Some manufacturers offer transducers with exposed elements so the signal isn't attenuated by a cap that would protect the device from foreign object damage and also inhibit dirt build-up. Others cap the elements but pressure balance to achieve better signal integrity.

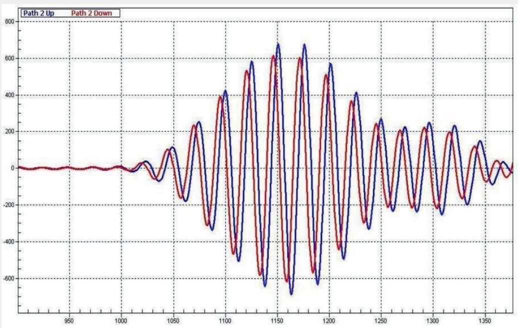


Figure 6. Typical ultrasonic pulse (raw signal) of a USZ 08

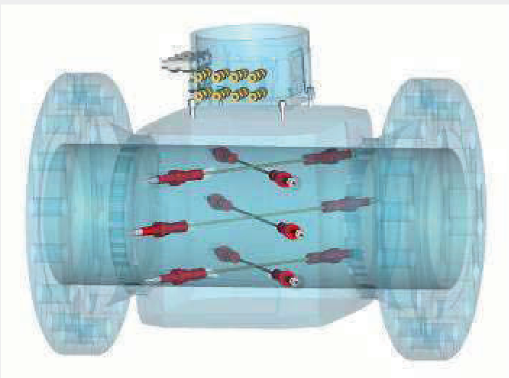


Figure 7. RMG by Honeywell path orientation

4.1.4 Pulse Detection Algorithms

An SPU that can consistently detect pulses in a challenging operating environment (i.e., noisy, dirty, etc.) is also a key element in devising a reliable meter. Ultrasonic pulses are affected by noise interference, and sometimes noise other than pulses may be detected by a SPU and erroneously interpreted as an ultrasonic pulse. This can result in large measurement errors.

Pulse mis-detection, also known as a "cycle jump" or "peak skip," might also occur, resulting in systemic transit time measurement errors (refer to **Figure 6** below for a depiction of a typical ultrasonic wave packet). Individual peaks in the pulse envelope are often used in manufacturer pulse detection algorithms as start/stop points for transit time measurements to achieve the resolution needed for accurate flow measurement. A peak skip is manifest when the SPU selects the wrong peak on which to start or stop transit time measurement, a fault that can be found using the path speed of sound correlation suggested in Chapter "Diagnostic Output: Meter Validation" below.

Therefore, manufacturers have applied various criteria to pulse validation (counting peaks or measuring individual peak amplitude, for example, and selecting a specific peak to use for transit time measurements). Another technique is to sample repetitive pulses and compare them to one another, which is often called "stacking." Again, trade-offs drive design choices; stacking can be an excellent way to validate pulses, however, it slows down processing, reduces the number of validated pulses, and as such, may provide statistically small time samples that reduce sensitivity and reliability in these measurements. Sometimes processing may be slow enough to cause data refresh rates that exceed one second.

4.1.5 Meter Bore

A meter bored to match pipe schedule is generally preferred to maximize the device's rangeability. Some manufacturers have found that a reduced or tapered meter bore can improve the velocity profile at low flow rates to compensate for use of fewer paths.. A reduced bore also "jets" the flow so the velocity field pulls away from the pipe wall in the measuring section and doesn't generate near-wall turbulence that can impact signal detection with lower amplitude (i.e., lower energy) pulses. A reduced bore may also skirt the need to offer meter bodies in various pipe schedules. Once again trade-offs are involved; in this case, some rangeability is sacrificed, and the opportunity exists for liquid and debris to collect at the low points at the entrance and exit of the meter bores to compensate for low energy transducers.

4.2 RMG by Honeywell Makes the Difference

With all these performance trade-off's in mind, RMG by Honeywell has selected the following to optimize its meter design [8, 9]:

4.2.1 Number and orientation paths

Six paths arrayed in an "X" pattern in three horizontal planes: a central plane, and two geometrically similar planes. This orientation permits measurement of swirl, cross-flow and asymmetry, as well as transparent path velocity weighting per the Gauss-Chebyshev profile model for compressible fluids (**Figures 7 and 8**). This path design was introduced by RMG by Honeywell at the end of 1998. So this is already more than 13 years ago and there is no reason up to now to change this path arrangement because of a couple of hundred successfully installed ultrasonic meters in the field, and with this design, it is possible to detect or measure the asymmetry, swirl, and cross-flow.

There is no compensation needed because the flow profile distortion is actually measured. Measurements with crossed paths ensure an optimal analysis of the velocity components v_1 to v_6 even in the case of asymmetries, swirl, and cross flow. The flow rate Q results from multiplying the weighted mean flow velocity by the pipe diameter (Equation 6). An additional Reynolds Number correction is not required.

$$Q = A \cdot \bar{v} = A \cdot (w_1 v_1 + \cdots + w_6 v_6) \qquad \text{(Equation 6)}$$

Where:

Q = Uncorrected flow (acfs or m3/s)

A = Pipe diameter (ft or m)

w_i = Weighting factor

v = Path velocity (fps or m/s)

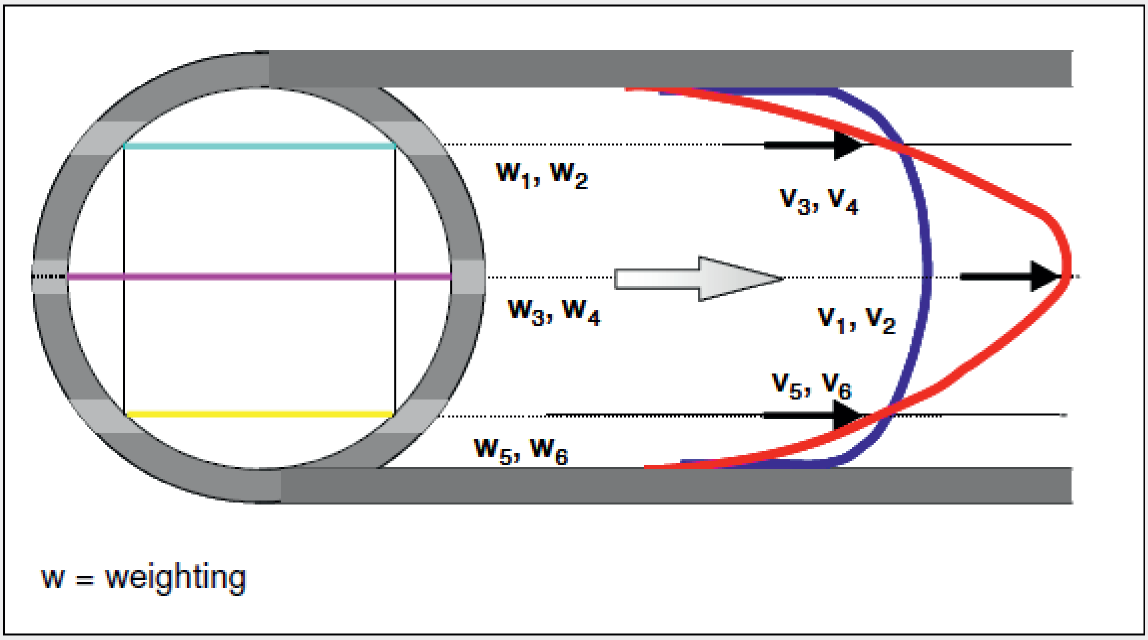


Figure 8. Path configuration of the RMG by Honeywell 6-path ultrasonic flow meter according to Gauss-Chebyshev

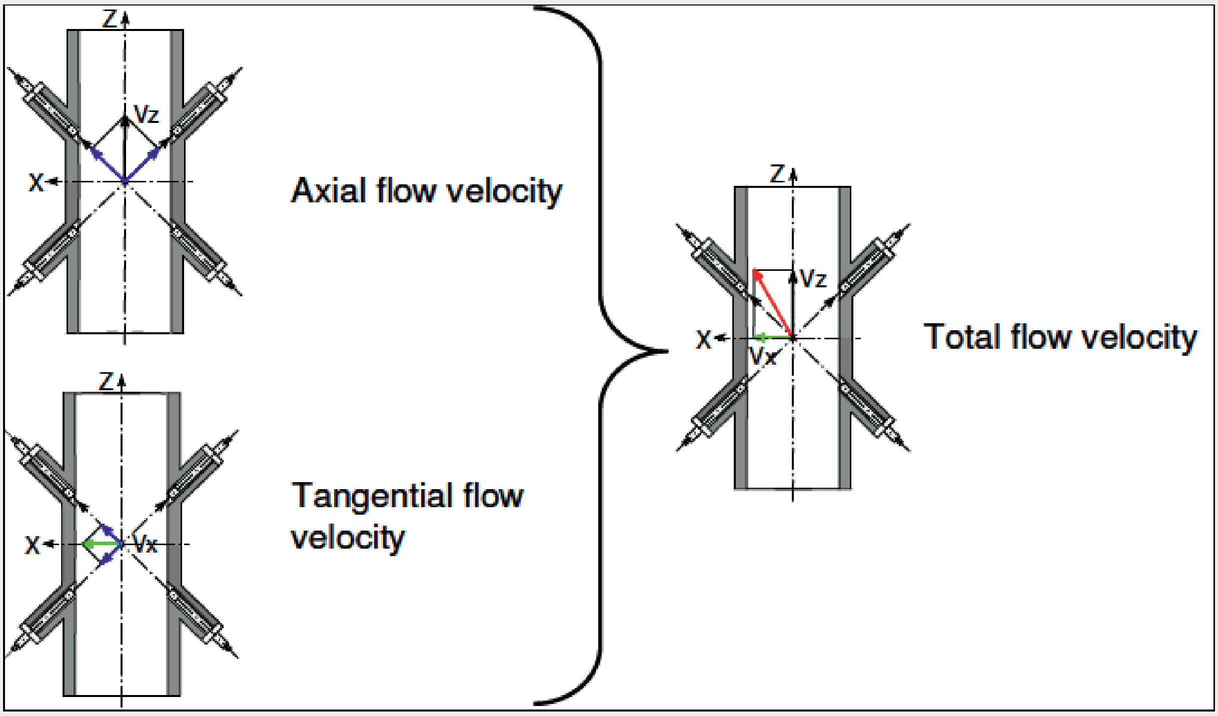


Figure 9. Vector analysis of the gas velocity in a single level

RMG by Honeywell has also opted to utilize a point-to-point pulse path to avoid problems with signal attenuation or warping that can occur with bounce path technology.

Pulse warping can be reduced by the use of reflectors (flats attached to the interior of the measuring section where pulses are bounced), however, reflectors compromise a full bore design and themselves generate turbulence. Note: previous RMG by Honeywell designs have utilized bounce paths with reflectors for DN 100 (4") and DN 150 (6"), but development of smaller transducers has allowed RMG by Honeywell to array 12 on a meter body to DN 100 (4") and DN 150 (6") diameters so that use of a point-to-point path construct is possible. As such, this path arrangement of six paths is now available from the smallest DN 100 (4") to the largest DN 1000 (40") ultrasonic meter available.

As previously discussed, the six paths arrayed in an "X" pattern in three horizontal planes allow direct measuring of the asymmetry of the flow profile. **Figure 9** shows this technique. The figure is separated into three sections:

- Section 1: Axial flow velocity.
- Section 2: Tangential flow velocity.
- Section 3: Total flow velocity.

The velocity in general is a vector. For further discussion, we must analyze the axial flow velocity in more detail. The axial flow velocity is the main flow direction of the gas in the ultrasonic meter (Z direction). The results of the ultrasonic meter measurement are the two blue vectors. The addition of the two blue vectors in a vector parallelogram results in the black vector (V_Z) which is the gas velocity at that level in the direction of Z.

The same consideration is valid for the tangential flow velocity. Here, the addition the two smaller blue vectors results in the green vector, the gas velocity in the direction of X (V_X), or in other words, the asymmetry of the flow profile.

Now we have two resulting vectors: one is V_Z for axial flow and another is V_X for tangential flow. By adding both vectors, we get the total flow velocity vector (the red vector in **Figure 9** in the total velocity section). The angle between the total flow velocity vector and the V_{Z-} vector is the so called swirl angle. In ideal conditions, the angle between both equals zero.

The USZ 08 ultrasonic meter from RMG by Honeywell is designed with three levels of measurement (2 paths on each of 3 horizontal planes), and the straight-

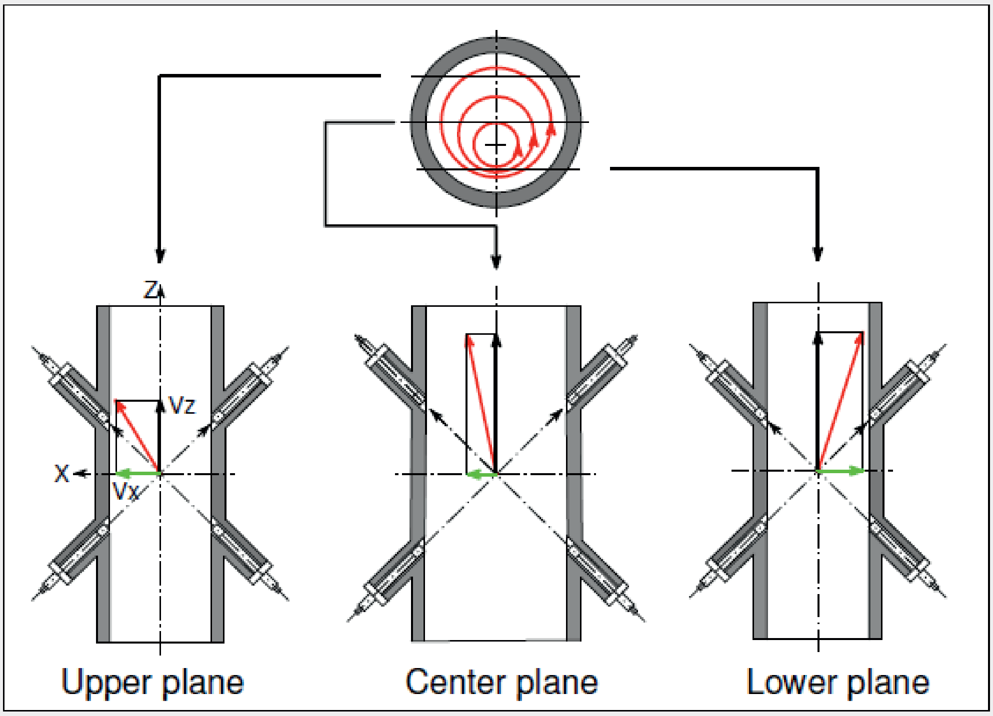


Figure 10. Vector analysis of the gas velocity in all three levels to cover the complete flow profile

forward vector analysis can be done in all three levels (upper plane, center plane and lower plane) as indicated in **Figure 10**. This path arrangement makes possible the best coverage of the flow profile with a minimum number of paths. Therefore, an additional Reynolds Number correction is not required because the USZ 09 is measuring the flow profile.

4.2.2 Transducer Design

RMG by Honeywell has developed compact, Titanium-encapsulated, high-energy transducers in 120 and 200 kHz models, making the unit resistant to dirt. Alternate frequency designs are available to help customers cope with noisy environments. The high amplitude capacity of the piezo-ceramic sensor permits the use of a dirt-resistant cap (which must still be thin shell Titanium to avoid attenuation) without the need to pressure balance the unit. **Figure 11** shows the 120 kHz transducer used in the USZ 08.

RMG by Honeywell transducers are EExd approved for hazardous areas, but are not intrinsically safe. Their detailed rating is Ex II 2G Ex de IIC T5 / T6 and the transducers can be used at pressures of up to 250 bar (ANSI 1500). Furthermore, wide measuring ranges (1 : 100 and above) with correspondingly high flow velocities of more than 40 m / s (131.2 ft / s) are possible with these robust transducers.

4.2.3 Detection Algorithms

RMG by Honeywell utilizes numerous criteria to validate pulses without compromising high firing rates (10 pulses per second). One of the criteria common to many manufacturers, including RMG by Honeywell, is peak identification and quantization in regards to position and amplitude in the pulse envelope. However, use of comparative analysis of pulses, or "stacking," has been avoided since it was found a burden for signal processing in challenging environments (i. e., noisy, turbulent, etc.), resulting in either data refresh rates exceeding one second, or a reduction of evaluated samples falling below statistical acceptability. As a result, RMG by Honeywell has implemented additional qualitative analysis to evaluate the pulse envelope and identify ultrasonic pulses, while still maintaining high firing rates. **Figure 12** shows an example of an USZ 08 ultrasonic meter installed in a gas station.

4.2.4 Meter Bore

The ISO 17089 – 1 Standard distinguishes between a "full bore" and "reduced bore" ultrasonic meter. A "full bore" ultrasonic meter has the same inside diameter as the flange diameter. A "reduced bore" ultrasonic meter has a smaller inside diameter than the flange diameter. ISO 17089 – 1 also recommends that changes in the inside diameters and protrusion should be avoided in order to minimize disturbances of the velocity profile. For this reason, RMG by Honeywell decided during the market introduction of the RMG USZ 08 to design it as a "full bore" ultrasonic meter without transducers intruding into the meter pipe (**Figure 13**).

The classification of "full bore" versus "reduced bore" sounds marginal, but **Figure 12** shows why it is not. This is a tandem bidirectional operation of the USZ 08 for a natural gas underground application. If one of the two meters was "reduced," it would create a flow profile disturbance for the other meter. So, in this kind of installation, it would not be a good design choice to use a combination of "full bore" and "reduced bore" ultrasonic meters. Rather, it is preferable to go ahead with a "full bore" ultrasonic meter for a very compact and cost-reduced installation.

If two "reduced bore" ultrasonic meters are the design choice then there has to be a straight pipe of 10 DN between the two units. In other words, the installation needs more space and the investment costs are higher compared to the previously discussed solution.

5. DIAGNOSTIC OUTPUT: METER VALIDATION

All commercially viable gas ultrasonic meters offer diagnostic outputs that indicate meter operating condition, up to and including the ability to judge whether or not volumetric output is accurate. The nature of the meter's operating principle helps define these outputs and also their interpretation.

As noted, ultrasonic meters depend on transmission and recognition of sonic pulses using precise timing measurements and known geometry (path length and angle) to accurately measure gas velocity. Manufacturers have incorporated signal (pulse) recognition and processing algorithms as well as highly accurate clocks to make timing measurements. Therefore, signal strength, signal-to-noise ratio and clock accuracy are fundamental to accurate and reliable meter performance. General (and rather generic) descriptions of meter diagnostics follow, but detailed descriptions are manufacturer-specific and beyond the scope of this paper.

5.1 Transducer Gain Level

Transducer gain level is a measure of the signal strength, or amplitude, at which each transducer is excited by the meter electronics to generate ultrasonic pulses. Gains are automatically adjusted by the meter electronics so that sufficient pulse amplitude is applied to enable pulse

Figure 11. Completely metal-encapsulated titanium sensor

Figure 12. USZ 08 of RMG by Honeywell installed in a tandem arrangement in a gas metering station for an underground storage facility in Germany (picture displayed with the permission of ENECO-Epe)

detection. Gains vary depending upon fluid density (i.e., flowing pressure, composition and temperature), and pulse reception quality.

Transducer gains should be considered as pairs (gain for the A and B side units rationed to one another is the most common method of treatment). If a transducer pair gains ratio breaks pattern with its previous footprint, or with the pattern of other units, it may indicate:

- Transducer fault.
- Dirt accumulation on a transducer.
- Other issue(s).

Transducer inspection will be required if a fault is detected in its replacement; otherwise, meter cleaning might be needed as a remedial action.

5.2 Transducer Signal-to-Noise Ratio

Evaluation of an individual transducer's Signal-to-Noise Ratio (SNR) provides feedback on whether noise is impacting meter function. For example, when the SNR falls to 1 : 1, the signal is overcome by noise and measurement stops. It is important to note that variation in SNR itself is not an indication that the meter's accuracy is in question, but rather that pulse recognition, (i.e., detection) is threatened. If pulses cannot be detected, measurement ceases.

The SNR for transducers facing a noise source is typically lower than for transducers facing away from the source. There is no remedial action that can be taken in regards to the meter if SNR falls to the point that measurement ceases. The only remedies available are to eliminate the noise source, change that source's frequency, or alter the meter's operating frequency by changing transducers. Alternatively, attenuating elements can be installed between the meter and noise source, but this is time-, labor- and cost-intensive, unless these elements are planned for and installed during the construction phase.

Figure 13. Meter bore – complete open inner diameter, no intruding sensors or reduction of the meter bore

5.3 Speed of Sound

Speed of Sound (SoS) is a critical and powerful diagnostic tool available in ultrasonic meters from which users can determine if a meter's operating performance has shifted. Two tests can be conducted using meter "measured" values for SoS:

- An absolute comparison of meter corrected SoS versus that calculated from the gas thermodynamic properties.
- A per path comparison to determine if an outlier on a particular path suggests its path length has changed (path length changes are either due to meter configuration input errors or debris build-up on transducer faces).

5.3.1 SoS Comparison to Calculated Value

Recall Equations 3 and 4 from the operating principle discussion:

Simple inspection of these equations reveals that the fluid velocity, v, and speed of sound, c, are both directly dependent on the meter's path length and transit time measurements. Essentially, meter pulse transit time measurements and path length data permit calculation of both v and c.

$$v = \frac{L}{2 \bullet \cos\varphi}\left(\frac{1}{t_D} - \frac{1}{t_U}\right) \qquad \text{(Equation 3)}$$

$$c = \frac{L}{2} \bullet \frac{(t_u + t_d)}{t_u \bullet t_d} \qquad \text{(Equation 4)}$$

The SoS in natural gas can also be calculated from its fluid properties of composition, pressure and temperature, with calculation standards adopted by the AGA 10 [10] as applicable. Therefore, it is possible to compare the "meter measured" value of SoS to that calculated with the AGA 10 equations. The meas ured versus calculated values should agree closely (a limit of +/– 0.25 % is typically used, but may need relaxing depending on the quality of compositional data).

Should a significant offset between the measured and calculated values be found, it indicates one or more of the following:

- The meter's path length(s) is in error.
- The meter's clock has shifted, causing transit time errors (or there is pulse misdetection, which is also an SPU problem).
- The data used to make the SoS calculation per AGA 10 is incorrect.
  - Compositional data is in error suggesting a GC issue
  - One or both of the pressure and temperature transducers is incorrect

These conclusions can be made because meter clock/pulse detection (or SPU function), path length and fluid data are the only variables that can cause disagreement between the measured and calculated value of SoS. Furthermore, it can be stated that good correlation of measured and calculated SoS "proves" that clock/SPU functions and path length are valid, and it can be concluded, therefore, that the meter factor has not changed!

5.3.2 Path Speed of Sound Comparison

Per path SoS footprints can be used to evaluate individual path issues related to path length, and possibly transducer function. Should an individual path's "as found" SoS deviate from the established foot print (once again, the footprint established during flow calibration and/or meter start-up should be used for reference), it can be concluded that this path's function (either path length or pulse detection on one of its transducers) is at issue. While it's true that a disparity could also be caused by a clock issue, the same clock is used for timing measurement on all paths, and were there a clock problem, all paths would probably shift in like fashion. Nonetheless, if the clock were at fault, the SoS comparison between meter corrected and AGA 10 calculated values would indicate the fault.

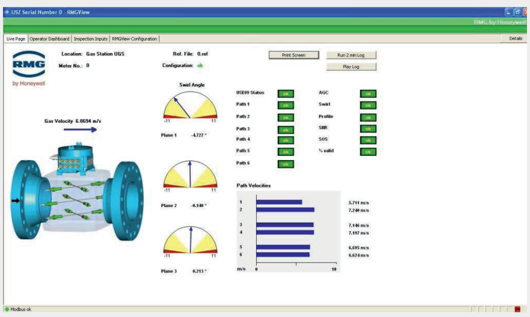


Figure 14. RMGView USZ 08 diagnostics and operation software "live" page

5.4 Profile Distortion

Profile distortions can be detected with comparison of a given manufacturer's diagnostic output for Swirl Angle and/or Asymmetry using a footprint technique similar to that suggested for Transducer Gains and per path SoS evaluation.

Users should review the available diagnostics for each of these quantities for a particular manufacturer's product, and consider the basis of calculation that each provides, since the variation in path geometries between manufacturers means that differences in the quality and sensitivity of these outputs also exists. Due to these sensitivity differences, it is not possible to provide a generic description for alarm treatment of swirl and asymmetry outputs.

However, any multi-path meter affords users the opportunity to also footprint the per path velocity patterns for its given geometry, which can then be compared with the "as found" velocity pattern. As a cautionary note, flow profiles vary with fluid velocity so any "as found" to footprint comparison needs to be made at roughly the equivalent velocity/Reynolds Number. To face this complication,it is better to select a meter manufacturer that provides ready outputs for swirl and asymmetry. It is recommended that users request manufacturers to specify the measurements and calculations made to generate swirl and asymmetry values to ensure they're understood. Thus the various path designs/geometries offered by manufacturers necessarily means the treatment, and therefore sensitivity, of these outputs also varies.

5.5 Conditioning Based Monitoring (CBM): The RMG by Honeywell Way

One of the advantages of ultrasonic meters, in comparision with all other flow measurement technologies, is the availability of a lot of additional information diagnostics beyond just delivering pulses or signals proportional to the gas volume. All this additional information and diagnostics is mostly handled through separate WindowsTM-based software. RMG by Honeywell has two ways of using additional diagnostics; one is the flow computer ERZ 2000 and the other is the WindowsTM-based software RMGView (**Figure 14**).

The RMGView parameterization and diagnostics software can handle the following CBM parameters "live" in parallel with the standard operational features:

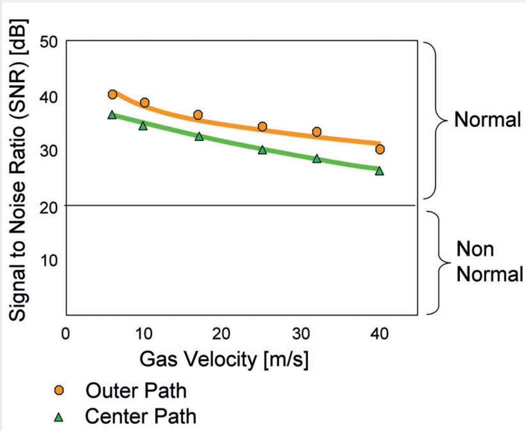


Figure 15. Signal-to-Noise Ratio (SNR) in relation to the gas velocity

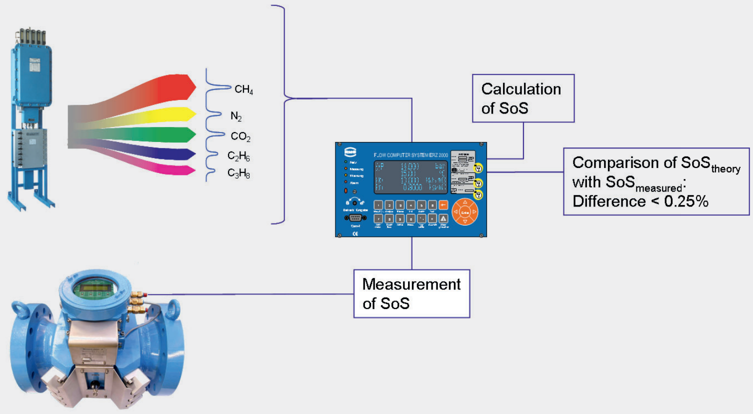


Figure 16. Live comparison of the SoS theorywith SoS measured due to AGA 10 [10]

- Monitoring of the AGC levels.
- Comparison of the Speed of Sound (SoS) of each path.
- Signal quality:
  – Signal-to-noise ratio (SNR) in dB
  – Valid samples in %
- Comparison of the Speed of Sound (SoS) due to AGA 10:
  – Estimated velocity of sound from the composition of the natural gas
  – Measured velocity of sound from the ultrasonic meter
- Evaluation of the flow profile:
  – Comparison of flow profile factors
- Monitoring the swirl angle φ.
- "Live" – RMG Precision Adjustment.

5.5.1 CBM – SoS Comparison of Each Path

The RMG by Honeywell path design uses 6 paths, and for each of the paths there is a measured Speed of Sound (SoS). If everything is okay (including the ultrasonic meter and the flow profile), then the ratio of the SoS of the single paths should be equal to one. Perhaps the following example makes this clearer. Here is the single SoS (C_1 to C_6) listed, and for example, the ratios C_1 / C_2 and C_1 / C_6 are calculated and they are both ≈1 so the measurement point is in standard conditions.

Example:

Single SoS per path:

$C_1 = 341.91$ m/s; $C_2 = 341.89$ m/s; $C_3 = 341.93$ m/s
$C_4 = 341.77$ m/s; $C_5 = 342.08$ m/s; $C_6 = 342.09$ m/s

Ratio of SoS of different path:

$C_1 / C_2 = 1.00006$
$C_1 / C_6 = 0.99947$
etc.

5.5.2 CBM – Signal-to-Noise Ratio

Signal to Noise ratio, or SNR, is a parameter indicating the degree to which "ambient" noise my be present in the pipe and can be used to pinpoint why a meter fails to report data at specific operating conditions. USM's depend on detection of sound pulses, but as noted previously, should the noise in the flowing stream, perhaps caused by a throttled control valve, be of sufficient amplitude in a frequency band corresponding to that of the meter transducers, interference can occur making signal detection impossible.

RMG by Honeywell's USM operates best (i. e. has optimal signal detection) when the SNR is above 20 db. Below that level, pulses may be rejected until noise overwhelms the meter's ability to detect them at all and measurement output stops. Honeywell is certified to operate for fiscal measurement purposes by PTB with accepted pulses to 40 % .This provides significant operating band-width even in the "Non-Normal" range of the graph above. Mesurement will theoretically continue until the SNR reaches 1, but somewhere between the span of 20 db to 1 db, accepted pulses will likely fall below 40 %, putting meter operation outside the PTB certified range.

Ambient noise that interferes with a USM's operation is usually generated by a throttled control valve installed in near proximity to the meter. A noise evaluation should be

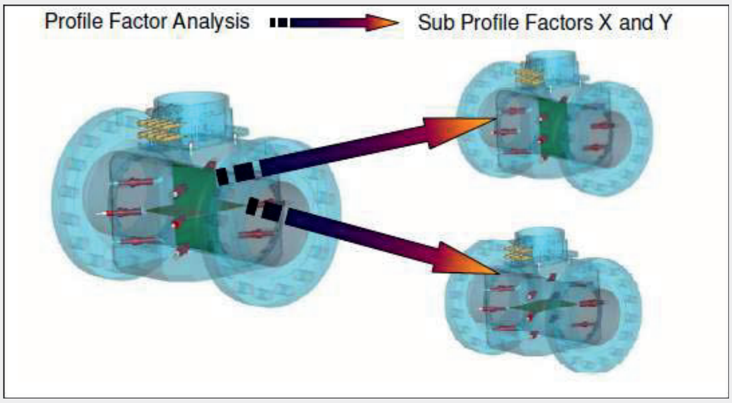


Figure 17. X- and Y-profile factors in a cross path arrangement

jointly conducted with the operator during the station's design phase if they propose to install such a valve, particularly a "quiet" trim valve, near a meter so that measures to isolate the meter from the noise source can be taken in during pipe work design (placing attenuating elements between valve and meter such as filters or blind tees).

A finding of noise interference after station build has occurred usually means an expensive piping re-work, but alternate frequency transducers are offered by Honeywell that might provide relief by moving the meter's operating frequency away from that of the offending noise, or if the operator can change the valve's trim cage or operating profile, these too may be solutions.

5.5.3 CBM – Live Comparison of SoS due to AGA 10 [10]

In larger gas stations, such as a gas border station, underground gas storage facility or a crossover station, a process gas chromatograph (PGC) is usually installed. A PGC separates the natural gas in its 11 main components, which are:

- Nitrogen, Methane, Ethane, Propane, i / n-Butane, i / n-Pentane, neo-Pentane and the sum of the higher boiling hydrocarbons called C_{6+}.

With this data and the formula published in the AGA 10 Report it is possible to calculate the Speed of Sound out of the composition [10]. This is the so-called theoretical Speed of Sound (SoS theory). On the other hand, the ultrasonic meter itself is measuring the SoS out of the differences in the transient travel time from up and down stream pulses. This is the measured Speed of Sound (SoS measured). How can users recognize this comparison in a "live" and "on-line" environment? The answer is shown in **Figure 16**. The data of the PGC is transmitted to the Flow Computer (ERZ 2000) and also the measured data from the ultrasonic meter (SoS measured) is transferred to the Flow Computer (ERZ 2000). It is a standard feature of the ERZ 2000 to calculate the Speed of Sound (SoS theory) according to the AGA 10, out of the gas quality data of the PGC. Now the Flow Computer has both data available: SoS measured and SoS theory. Finally, it is very easy to compare both values. In a normal case the difference of the two is < 0.25 %.

In cases with larger differences, what is wrong? It can be the PGC, USM, temperature or pressure measurement. In other words, a more detailed investigation is necessary. In more than 80 % of these cases it helps to start a manual calibration of the PGC and the operation conditions back to normal. So, based on this experience, the question is: how is checking done? Does the PGC control the USM or the other way around? Regardless, this comparison is a very simple and helpful tool to check the complete metering run.

5.5.4 CBM – Flow Profile Factors

Up to now, our CBM discussion has addressed application of the RMG by Honeywell USM's sophisticated diagnostic outputs to indicate whether a functional issue has occurred with the meter. But what of an operational issue that might not be readily apparent from the functional diagnostics of SoS or SNR? A change in flow profile induced by blockage, protrusions or pipe contamination can affect fiscal output with little noticeable affect in the diagnostics discussed til now. So we must also address operational diagnostics to determine whether such a profile change has occurred and then evaluate it's potential impact on meter accuracy. This is best accomplished using individual path velocities to diagnose profile changes from baseline, and in that evaluation, a manufacturer's path orientation design choice has great impact.

Depending on the design choice, the flow paths and their arrangement define the type and number of profile factors in an ultrasonic meter. With RMG by Honeywell, six paths arrayed in an "X" pattern in three horizontal planes results in two main categories of profile factors (**Figure 17**):

- X-profile factor
  - Flow profile in the horizontal direction using the Sensor-Cross-Planes
- Y-profile factor
  - Indicates the vertical portion of the flow profile

In normal conditions the X-profile factor equals the Y-profile factor (X = Y). But in a disturbed flow profile the profile factors are different from one another (X ≠ Y). This indicates the integral, not closed for the flow profile, is not completely covered. In other words, some parts of the profile are missing. To clarify this situation, further analysis of the sub-profile factors is necessary (**Figure 18**). All profile factors mentioned in this chapter can be tracked and displayed in real-time with the RMGView software.

The X-profile factor itself comprises two sub-profile factors (**Figure 19**):

- X_1 profile factor.
- X_2 profile factor.

The X_1 profile factor is created by the comparison of the center plane with the upper plane, and the X_2 profile factor is built from the comparison of the center plane with the lower plane. Under normal conditions $X_1 = X_2$.

In comparison to the X-profile factors , the Y-profile factors are deducted in a similar way. The Y-profile factors are shown in **Figure 20**. The Y-profile factor is divided into two sub-profile factors: Y_1 profile factor and Y_2 profile factor. The Y_1 profile factor consists of the $Y_{3,1}$ and $Y_{3,5}$ profile factors , and the Y_2 profile factor consists of the sub-profile factors $Y_{4,2}$ and $Y_{4,6}$. $Y_{3,1}$ and $Y_{4,2}$ profile factors are created by the comparison of the center plane with the upper plane. $Y_{3,5}$ and $Y_{4,6}$ profile factors are built from the comparison of the center plane with the lower plane.

From **Figure 20** it is also obvious that if there are no crossed paths in one plane it is impossible to build Y-profile factors. The Y-profile factors indicate the swirl in the flow profile as shown in **Figure 21**. Here is shown the area of the Y_2 profile factor. If there is swirl in the flow, the areas are indicated with +/– for faster and lower gas velocities.

The above consideration was somehow theoretical. So it comes to the question: how does tracking help in daily live metering systems? For example, an ultrasonic meter is

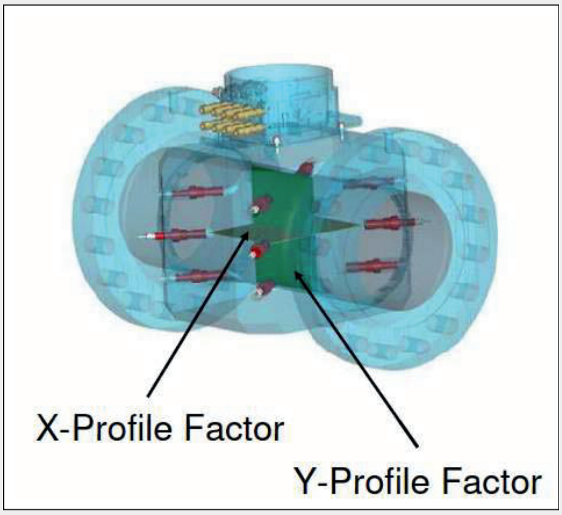


Figure 18. Flow profile factor analys is done separately for the X- and Y-profile factors

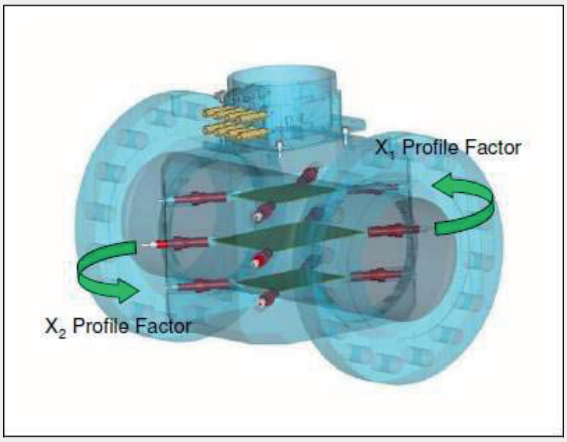


Figure 19. X-profile factor separated in two sub-profile factors: X_1 and X_2 profile factors

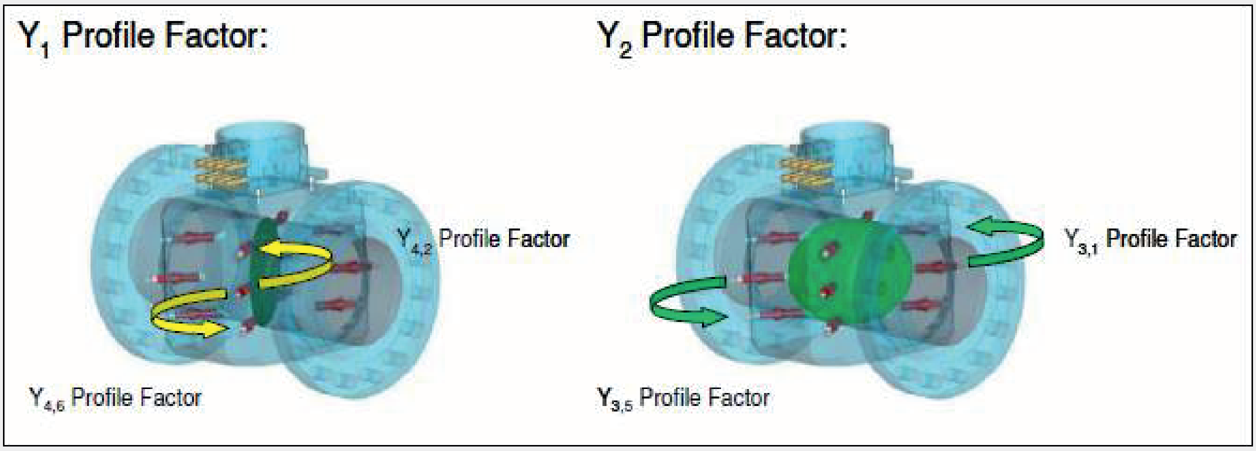


Figure 20. Y-profile factor separated in two sub-profile fa

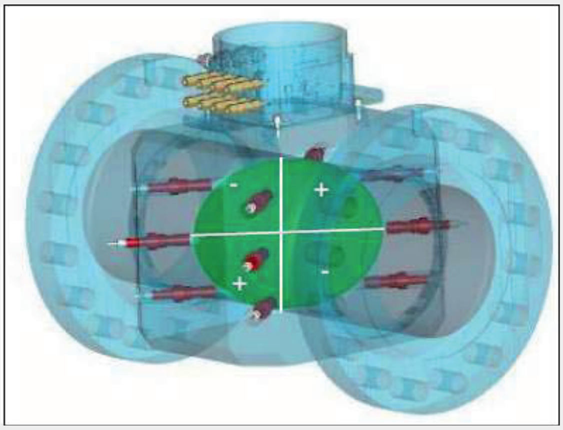


Figure 21. Picture showing how the Y_2-profile factor changes if swirl is in the gas flow profile

installed in a metering skid for years and is in operation 24 hour a day, 365 days a year. During this time the inner surface of the meter may change due to deposition of dirt or liquid, or as a result of roughness created rust. **Figure 22** shows a standard turbulent flow profile shortly after the start up of the ultrasonic meter. **Figure 23** shows graphically what can happen to the inner surface of the meter after years of operation. This figure also explains in a very demonstrative way why reflective ultrasonic meters may have problems after years of operation, and why they are limited in gas velocity. How does this change to the inner surface influence the flow profile? The answer is shown in **Figure 24**. The gas velocity vectors at the outer planes will be reduced and the gas velocity at the center plane will be fast compared to the ideal condition. This is also reflected in the profile factors X_1 and X_2, which will increase.

As described earlier, the profile factors can be tracked and displayed "live." Therefore, the USZ08 is able to detect these kinds of disturbances on-line as a standard feature. This can be very clearly demonstrated as it happened in one gas station recently. The status of the diagnostics is as follows:

- Comparison of SoS due to AGA 10 → Result: OK.
- Signal Qualitiy (SNR) → Result: OK.
- Profile factors X_1 / X_2 show a significant difference → WHY?

The answer is indicated by **Figure 25**. Over time rust formed and there was more rust on the top than the bottom. This effect is evidenced by the change of the profile factors X_1 / X_2 and is directly indicated by the USZ08 of RMG by Honeywell.

5.5.5 CBM – Swirl Angle

The swirl angle is the difference of the gas velocity vector from the axial direction (**Figure 26**). How the swirl angle is measured is explained earlier in detail. The swirl angle can be directly monitored on the "live" page of the RMGView software for all three levels (**Figure 27**). At standard conditions the sum over all three swirl angles equals zero. In cases where the sum of all swirl angles is ≠ zero, the flow profile is not 100 % captured and the measured flow can be lower or higher than the real flow.

5.5.6 CBM – "Live" – RMG Precision Adjustment (Patented [11])

Up until now, it has been state-of-the-art to perform a Zero Flow Verification Test to adjust an ultrasonic gas meter. This test is described in AGA 9 (6.3) [1]. This adjustment is necessary due to the fact that besides the time of flight of the ultrasonic pulses, delay times also occur within the system, which are caused by the signal processing electronics, properties of the transducers, and the calculation algorithms. As these delay times cannot be determined directly, they must be determined by a costly measurement.

$$t = L / C_{th} + t_w \quad \leftrightarrow \quad t_w = t - L / C_{th} \qquad \text{(Equation 7)}$$

Where:

t = Transit time upstream (sec)

L = Path length (ft or m)

C_{th} = Theoretical Speed of Sound (fps or m/s)

Assuming there is no flow through the meter, the time of flight of a sound pulse is given by the following equation:

To determine the system delay time t_w all other measured values of this equation must be determined exactly. The time of flight is directly measured by the ultrasonic gas meter. The path length L can be measured exactly, at least for all meters with face-to-face arrangement of the transducers (working without reflections). More challenging is the determination of the theoretical Speed of Sound C_{th}. It can be calculated by the use of state-of-the-art algorithms (AGA 8 / AGA 10), taking into account the gas composition and the actual gas temperature and pressure. To minimize measurement uncertainty, it is recommended that the meter be filled with a gas having a known Speed of Sound (e.g., N_2). Pressure and tempera-

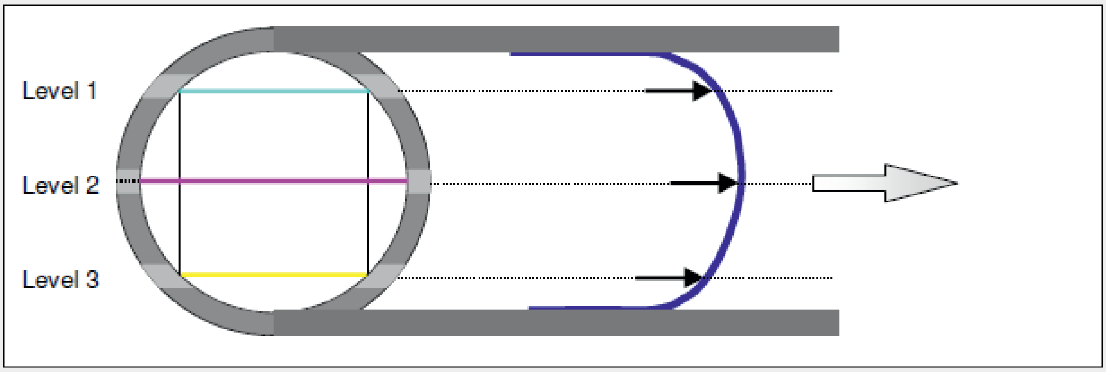


Figure 22. Standard flow profile for turbulent flow

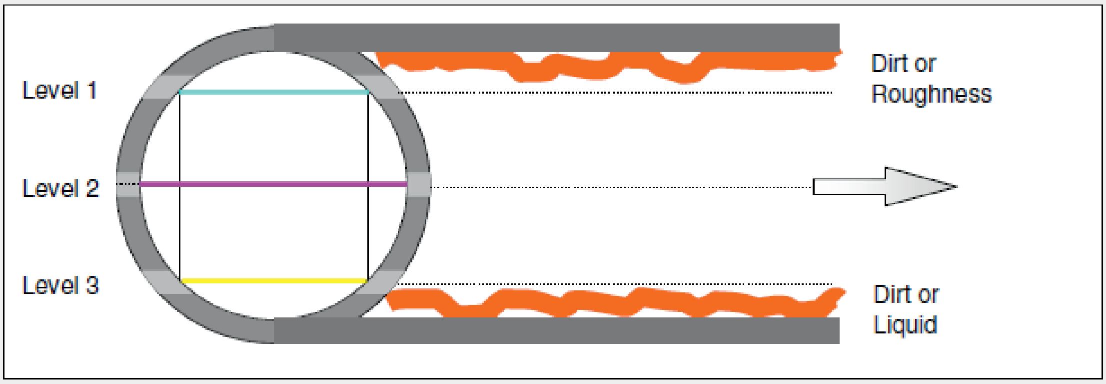


Figure 23. The inner surface of the meter or the entire pipe will change over years of operation, due to deposition of dirt or liquid in the button

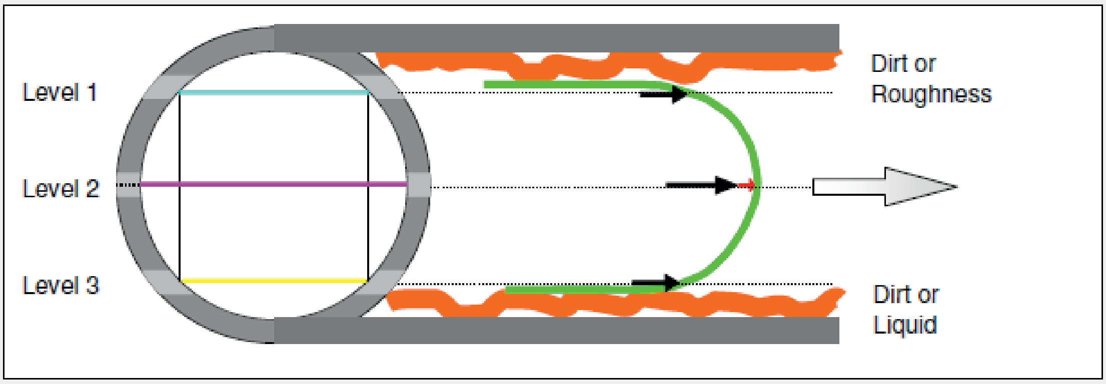
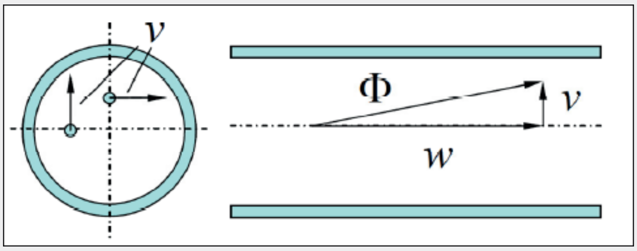


Figure 24. Demonstration of how the flow profile and X-profile factor will change

Figure 25. Example of a contaminated USM with inlet spool. This contamination could be detected with the X-profile factor analysis.



Where:

Φ = Swirl angle (°)

v = Spin component of the velocity (fps or m/s)

Figure 26. Graphical explanation of the swirl angle

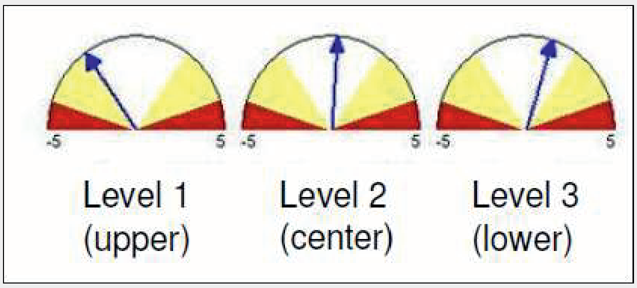


Figure 27. Pie meters for the three levels showing "live" swirl angles in the RMGView software package

ture must be kept stable during the procedure and measured precisely. Most critical is the measurement of temperature, as levels of differing temperatures may occur inside of the meter.

Obviously, this method includes various possible sources of errors, which contribute to and increase the measurement uncertainty. As such, it is not a "live" verification of the delay time.

The RMG by Honeywell ultrasonic meter USZ 08 and its electronics USE 09 allow for a precise adjustment of the delay time by a new method, which avoids all disadvantages of the classical method described above. For this adjustment, two measurements have to be done per shot:

- Time of flight between S_1 and S_2: t_1 (direct measurement, **Figure 28**).

$$C_1 = L/(t_1 - t_w) \qquad \text{(Equation 8)}$$

$$C_2 = 3 * L/(t_2 - t_w) \qquad \text{(Equation 9)}$$

$C_1 = C_2$ = const. (for short times)

Combination equation 8 and 9 and rearrange it to t_w:

$$t_w = (3 * t_1 - t_2)/2 \qquad \text{(Equation 10)}$$

Where:

$t_{1,2}$ = Transit time (sec)

L = Path length (ft or m)

$C_{1,2}$ = Speed of Sound (fps or m/s)

- First echo on the receive sensor: t_2 (reflective measurement, **Figure 29**).

The fundamental equations are:

Instead of the time of flight t_1 for direct distance between sender and receiver, the time of flight t_2 for the first echo, reflected on the receiver and sender, is measured. According to **Figure 29**, the path length in this case has tripled. Both measurements provide a measured value for the speed of sound (C_1 and C2). Out of these measurements the delay time can be determined precisely and shot by shot! That means LIVE!

This new method provides the following unique advantages:

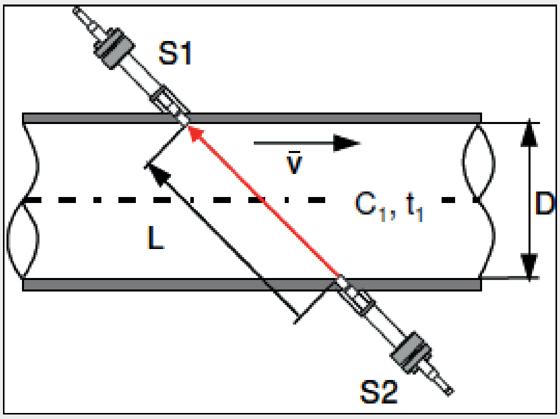


Figure 28. Direct USM measurement of signal

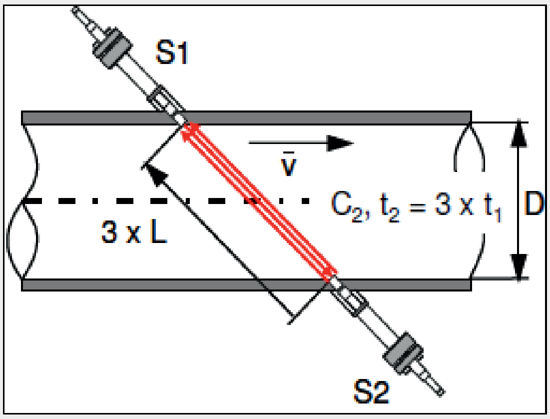


Figure 29. Reflective measurement (echo measurement)

- The composition of the gas inside of the meter must not be known.
- The measurement is independent of the theoretical value of the Speed of Sound.
- As the absolute value of the Speed of Sound is not needed, pressure and temperature do not have to be measured.
- The determination of the delay time is done automatically.
- Higher accuracy in the determination of Speed of Sound.
- Live monitoring of the altering process of the transducers.
- Temperature, pressure, moisture, aging of sensors, and electronics have no influence on the calibration result.
- A verification of the meter can be performed in the field under operating conditions.

Figure 30 shows the influence of the live dry calibration compared to the standard modus without echo measurements. As we have explained, this echo measurement allows for a much more accurate determination of the Speed of Sound. The determination of the Transit Time is also more accurate, and this implies that the flow measurement overall is higher than conventional ultrasonic meters without echo measurements.

6. CONCLUSION AND OUTLOOK

Today, ultrasonic meters are widely accepted for custody transfer and allocation metering because of their technical advantages over other flow metering technologies like turbine meters and vortex meters. This situation is also due, in part, to advancements in ultrasonic meter technology and establishment of the ISO standard [2] in 2010.

Ultrasonic meters are now the overwhelming technology-of-choice for large capacity gas measurement stations because of their reliability and rangeability. Every year, more and more ultrasonic meters are sold (with greater pressure on pricing), resulting in the development of smaller size meters (< DN 100 [4"]) for distribution networks and downstream applications. For these applications, the installation requirements for ultrasonic meters

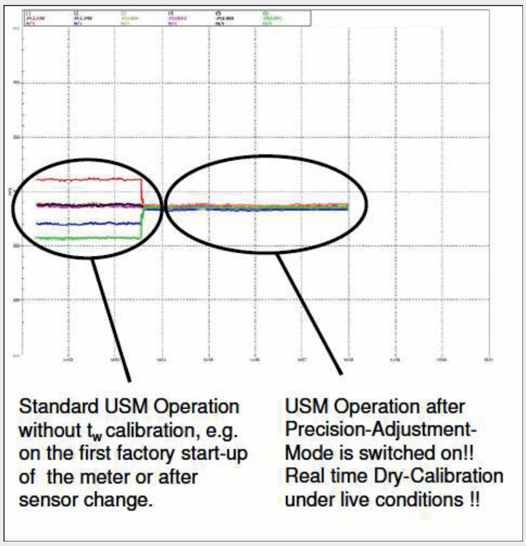


Figure 30. Effect of the RMG by Honeywell precision adjustment

have to be simplified – a challenge to be met in the near future by improvements to the technology.

Another reason for the on-going success of ultrasonic meters is the potential to provide operators with simple diagnostic techniques to validate meter integrity in the field, such as RMG by Honeywell's precision adjustment measurement and the comparison of Speed of Sound diagnostics. The coming years will bring additional diagnostic advancements within ultrasonic meters, which will simplify installation, operation, and meter validation.

There is also a clear trend towards ultrasonic meters in larger sizes. Unfortunately, there are no test rigs capable of serving these applications in a proper way. This situation is coupled with the challenge of obtaining a time slot on a test rig for highpressure calibrations. ■

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AUTHOR

Achim Zajc
Product Marketing Manager
Gas Metering
Honeywell Process Solutions
RMG Messtechnik GmbH
Butzbach | Germany
Phone: +49 6033 897 138
E-mail: achim.zajc@honeywell.com