Ultrasonic Flow Meters

P. BAKER (2013)

Types

A. Time of Flight (a.k.a. - TOF, Differential Transit Time)
B. Doppler Frequency Shift
C. Hybrid
D. Open Channel - Acoustic Discharge Velocity Profiling/Indexing (Time of Flight, Pulsed Doppler)
E. Open Channel (Non-Contacting - Flumes/Weirs) - Refer to Chapter 54

Applications

A. Liquids in full, closed conduits or man-made channels - must be acoustically conductive, clean & homogeneous with little or no solids or bubbles; (N.B. Recent technical developments are overcoming some of these limitations - Refer to New Developments)
Gases in closed conduits - must be clean with minimal dirt/dust/moisture
(N.B. Recent technical developments are overcoming some of these limitations - Refer to New Developments)
B. Liquids with solids content; concentrations from 0.2 to 60%, depending on the particle size & composition or with entrained gas or air bubbles – liquids must be acoustically conductive in full pipes or closed conduits. For partially full pipes see option D
Liquids, relatively clean, single phase, but with a continuous turbulent flow profile (Re > 8000) - application may have limitations, check with manufacturer.
C. Same as A & B
D. Open channels (rivers, canals, irrigation streams, penstocks, etc.) or partially filled conduits (industrial outfalls etc.)

Velocity Limitations

A. Liquids: 0.3 to 15 m/s; (1 to 50 ft/s)
Gases: 0.03 to 40 m/s (0.1 to 131 ft/s)
B. Liquids: 0.07 to 9 m/s (0.25 to 30 ft/s) *Slurries: Minimum velocity for solids to stay in suspension is about 0.75 m/s (2.5 ft/s) bubbles require 1.8 m/s (6 ft/s). Caution: Due to the abrasive nature of some slurries max flow should be limited to 3 m/s (10 ft/s).
C. Same as A & B
D. Velocity: +/-5 m/s (+/-16 ft/s); Depth: 0-30 m (0-98 ft)

Process Temperature Limits

A -196 to 260°C (-321 to 500°F) (manufacturer & transducer specific)
B. -10 to 60°C (-14 to 140°F)
C. Same as A & B
D. N/A

Design Pressure

A. Up to 207 bars (3000 PSIG) for wetted; unlimited for clamp-on
B. Up to 207 bars (3000 PSIG) for wetted; unlimited for clamp-on
C. Same as A & B
D. Atmospheric to 3 Barg (42 PSIG)

Materials of Construction

A. Spools & transducer probes: steel, polyurethane, nylon, stainless steel, or alloys; Transmitter Housing: plastic or cast Aluminum
B. Spools & transducer probes: polyurethane or stainless steel; Transmitter Housing: plastic or cast aluminum
C. Same as A & B
D. Polyurethane, Titanium, Stainless Steel

Availability for Pipe Sizes

A. 3 mm to 6 m (0.125" to 240") diameter
B. 13 mm to 1.8 m (0.5" to 72") diameter
C. Same as A & B
D. Check with Manufacturer

Straight Pipe Required

A 10 to 20 diameters upstream, 5 downstream; more diameters or flow conditioners required for very disturbed flow profiles

B. 10 to 20 diameters upstream, 5 downstream; more diameters or flow conditioners required for very disturbed flow profiles

C. Same as A & B

D. N/A

Accuracy (Measurement Uncertainty)

A. From 0.5% (R) to 3% (R) . For further explanation please see the discussion under Calibration later in the chapter. (See Reference #2)

B 2 to 5% (FS)

C. Same as A & B

D. 2- 5% (R)

Capital Costs (Exclusive of Installation)

A. $2,500 to $150,000+USD

B. $3,500 to $10,000+ USD

C. $4,000+ USD

D. $5,000 to $10,000+ USD

INDEX:

INTRODUCTION

Ultrasonic flow meters were first introduced in Japan, in 1963, by Tokyo Keiki Inc. In 1972, Controlotron (now Siemens A.G.) became the first U.S. manufacturer to introduce them in the United States. During the 1970s and early 1980s, the process control industry had high expectations for these devices. It was anticipated that Ultrasonic Flow Meters could be installed without requiring process shutdown (clamp-on types), the clamp-on style would be economical for larger pipes, inn addition Ultrasonic Flow Meters would not generate any pressure drop and could provide wide rangeability for bi-directional flow. Unfortunately, detailed knowledge of the required process parameters and installation constraints/requirements necessary for a successful installation of early meters were not yet fully understood. As a result, the high expectations for the successful application of these first generation ultrasonic flow meters were not realized. Subsequent innovations and advances in technology, improvements in the science of Ultrasonic Flow Metering, a better understanding of the characteristics of process flows and the importance of proper installation addressed these issues so successfully that Ultrasonic Flow Metering technology today is exploding as a flow measurement solution.

This discussion of Ultrasonic Flow Meters begins with a review of the physical meter configurations that are currently available regardless of their principle of operation, whether they are intended for portable use or permanent mounting or for use on gases or liquids.

All metering systems consist of three components. They are: 1/ an electronics transmitter or signal processing unit, 2/ one, two or more transducers, and 3/ the necessary interconnection cables.

The portable version includes a battery operated, self-contained handheld electronics unit, quick disconnect signal cables and one or two clamp-on transducers, the size of which being dependent on the application. Permanent mount meters comprise of the electronics in a larger housing (for remote or local mounting with respect to the process measuring point), conventional low noise cables and the transducer(s). The number of transducers required is technology and application dependent.

The transducers come in two mounting configurations. 1/ Separate, stand alone, portable transducers that are mounted by the user in the desired measurement location. or 2/ Transducers that are permanently mounted to the pipe or a pipe spool piece, either integrally bonded to the outside of the pipe, inserted through the pipe wall and in contact with the actual process or precision mounted to the interior of the pipe wall (larger applications). The last two mounting options of the second configuration are referred to as 'wetted'.

Both mounting styles have their advantages and disadvantages. There are several options available as to the construction of the transducers and pipe section including: hot-tap or removable wetted transducers, the transducer materials for wetted apps, transducer shapes, special calibrations and assorted pressure ratings for spool piece meters. Table 1 illustrates the advantages and disadvantages of each in full flow, closed pipes under 40"(1m). Larger meter installations are also discussed later under Measurement, Uncertainty, Calibration and Installation.

TABLE 1

User mounted Clamp-on transducers	**Integral spool piece with internal or external mounted, or 'wetted' transducers**
Lower cost	More expensive
Reasonable accuracy, can be flow lab calibrated if piping parameters & process details provided	Can be flow lab calibrated to custody transfer standards
Easily re-purposed	Process shut down required for re-deployment
Pressure only limited by pipe	Pressure limited by transducer mounting
Non-intrusive, no disturbance to flow profile	Transducers inserted in flow can cause integration error (See Reference #3)
May have limitations depending on pipe material, presence of lined pipe, pipe size etc.	WYSIWYG -Spool piece is a known quantity, no guess work
Acoustic coupling of transducers critical for clamp-on transducers	No acoustic coupling required

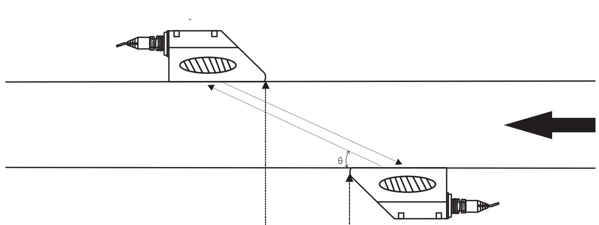
THEORY OF OPERATION

A) TIME OF FLIGHT (TOF) TRANSIT-TIME ULTRASONIC FLOW METERS

As the name implies, these devices measure the process velocity by measuring the time taken for ultrasonic wave pulses to traverse an interior length of pipe section, both with and against the flow of the process. Figure 26.1 is a diagram of transit-time clamp-on type transducers mounted on a pipe. Time of Flight meters simultaneously transmit ultrasonic signals (called a chords) in fixed directions (called the paths) up and down or across the center of the pipe towards the matching transducer. When the signals are received, the resultant transit time difference between the chords is proportional to the flow velocity. There can be and often is more than one set of transducers as in custody transfer applications and gas measuring meters. The process flow is found by calculating the time difference between the upstream travelling beam(s) and the downstream travelling beam(s), adjusting each beam for its angle of incidence to the axial flow (Snell's Law) and then integrating the beam(s) with the pipe's inside area to determine the resultant flow. Transmission paths for the transducers are available in different pre-determined configurations within the pipe. Examples are: 'Z', 'V', 'N' or 'W' as illustrated in Figure 26.2 below. The longer travel distances in V, N & W transmission patterns allow a better time resolution of measured velocities in small pipes. The transit time is measured in nanoseconds and picoseconds. The frequency of the transmitted signal is beyond hearing so in the +20,000Hz range. Time of Flight meters are not applicable for measuring transitional flow profiles and therefore the flow should always be in the laminar (Re<2500) or turbulent (Re>8000) ranges.

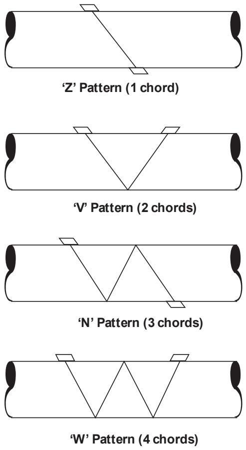
Figure 26.1

. Courtesy of Alia Group, Inc.



Graphical Representation of Time of Flight Transducer Installation

Figure 26.2



Graphical Representation of Z, V, N & W Path Patterns for TOF Meters

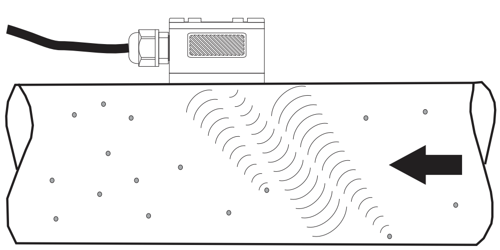
B) DOPPLER ULTRASONIC FLOW METERS

In 1842, Christian Doppler, an Austrian mathematician/physicist, discovered that the wavelength of sound received by a stationary observer from a sound source moving toward that observer, appeared to be shorter (of higher frequency), than that same wavelength received when the sound source was moving away from that same observer. In a Doppler flow meter, the transducer projects an ultrasonic beam at a frequency of ~0.5 MHz upstream into the flowing stream. Entrained particles or air bubbles then, collide with that transmitted sonic beam and reflect it back to the transducer. Any frequency difference between transmitted and reflected velocities, referred to as the “beat frequency", is due to the Doppler principle. This value is corrected for the angular incidence (Snell's Law) of the chord to the process stream and the frequency shift of the reflected beam is directly proportional to the process velocity.

As shown in Figure 26.3, an ultrasonic wave is projected at an angle through the pipe wall into the liquid by a transmitting crystal in a transducer mounted outside the pipe. A reflected chord is bounced back by the particles/bubbles in the process and converted into a velocity value.

Alternatively, two transducers can be placed in locations upstream and downstream of each other on the pipe similar to a transit time arrangement. The first transducer transmits a signal against the flow which is then reflected back by the second transducer to the original transducer. The electronics then compares the frequencies of the transmitted beam and the reflected beam. If velocity is present, a Doppler shift is observed and the flow is calculated. These types of meters are also known as 'sing-around' meters. They are very common in the medical industry finding use in spirometers and echocardiography. Doppler shift technology is available in both hand held and permanent mount configurations.

Figure 26.3



Graphical Representation of Simulated Ultrasonic Path Pattern for Doppler Meters

C) HYBRID FLOW METERS

There are several types of meters that could be classified as Hybrid. The first meters combine Time of Flight and Doppler shift technology into one meter. The choice is switch selectable with plans for auto select in the future. This instrument is available with either clamp-on or fixed mount transducers. Recent developments include dual transducer inputs in one transmitter that would allow monitoring of two pipes or monitoring two locations on the same pipe. These meter are also available with dual temperature inputs for BTU calculations. (See Reference 9). A recently introduced technology originally developed for underwater acoustic applications and offshore down hole oil and gas production, utilizes a sonar based array to sense the pressure fluctuations or eddies created in turbulent flows. From this information the meter calculates the volumetric flow. Simultaneously, these meters measure the speed of sound propagation in the process and from this, calculate the process's composition or if a slurry its density. (see Reference #12).

D) OPEN CHANNEL - TIME OF FLIGHT OR PULSED DOPPLER ACOUSTIC DISCHARGE FLOW METERS

Open channel flow meters, commonly used to accurately determine the flow of everything from irrigation ditches to large waterways, use either time of flight or pulsed Doppler technologies to measure the channels flow velocity. Time of flight, as explained above, works by beaming ultrasonic chords in both directions, across the channel at different levels, then comparing their travel time to calculate the velocity and then integrating those velocities with the channel's level, measured concurrently, to determine the flow.

Pulsed Doppler is similar to the Doppler Effect only, instead of continuously transmitted chords, the ultra sound is pulsed at pre-determined intervals upstream across the breadth of the flow stream. The instrument then calculates the flow velocities based on the reflected signals. The instrument, pre-configured to know the angles of the velocity in the cross-sectional area of the stream or channel is then is able to accurately calculate a velocity profile (index). The stream or channel's cross-sectional profile has been mapped and recorded in advance. The instrument then integrates the indexed measured velocities of the flowing channel with a depth measurement (either hydrostatic or ultrasonic/sonar) and the mapped cross-sectional profile to calculate the open channel flow or the total flow discharge.

E) OPEN CHANNEL (Non-Contacting - Flumes / Weirs) Refer to Chapter 54

Other methods of measuring open channels using flumes and weirs are discussed in Chapter 54.

MEASUREMENT UNCERTAINTY, CALIBRATION & INSTALLATION

OVERVIEW

The success of ultrasonic flow metering is based on two interdependent conditions, MEDIUM & LINKAGE. The medium is the material/process through which the sound is travelling (pipe wall, process, acoustically conductive process etc.). Linkage is the integrity of the bond between adjacent mediums (transducer and pipe wall, pipe wall and lining, lining or pipe wall and the process etc.). It can be immediately seen that wetted transducer installations will exhibit superior results due to the direct contact of the transducer and process. Conversely clamp-on installations will require more attention to transducer mounting and a thorough knowledge of the installation. This is the reason that measurement uncertainty, calibration and transducer installation are interdependent and will be discussed together. One of the most important and perhaps the most misunderstood specifications in Ultra Sonic Flow Meter specifications is the accuracy or measurement uncertainty statement. Measurement uncertainty is composed of two types of error: 1/ Precision Error and 2/ Systematic error. (See Reference #2)

The Precision or Random Error is a function of the system's overall hardware design and is reaffirmed by the manufacturer in the carefully controlled environment of a flow lab. This is the error listed on the manufacturer's spec sheet. Precision error does not change unless the instrument has been tampered with or components have been replaced. It is however, very difficult to replicate the carefully controlled conditions of the flow lab in the field. This introduces the second type of error, systematic error.

Systematic or Bias error encompasses all factors that are related to the meter's actual field installation. Some of these include: the pipe's outside surface, the pipe's inside surface, a lined pipe (if present), the bonding of the liner to the pipe, a coating or build up in the pipe, pipe eccentricity, pipe roundness or ovality, pipe material, environmental factors and flow profile to name some of the more common ones. The Systematic Error can add up to 5% (R) or more error to the total uncertainty and can vary from application to application.

The accuracy statement or Total Measurement Uncertainty as it is more correctly referred to, is a mathematical calculation that combines (using RSS) both the Precision Error and the Systematic Error.

In the following paragraphs, both types of error will be discussed with the focus on the potential factors contributing to the Systematic Error component of each meter type and methods of reducing these errors. (See Reference #2)

A) TIME OF FLIGHT (TOF)/TRANSIT-TIME ULTRASONIC FLOW METERS

Portable or Permanent Mount TOF Instruments with Clamp-on Transducers

The manufacturer's accuracy statement of most portable TOF meters nominally claim a precision error of +/- 1 to 2% (R) on a 60:1 turndown with a repeatability of +/- 0.2% (R). Because the main uses of meters with clamp-on transducers vary widely from simply confirming flows to setting up VFD pump systems by tracking the flow outputs, detailed calibrations on all potential applications are not feasible. Instead, many portable and permanent mount units that use clamp-on transducers have internal sub-routines that provide feedback to aid in confirming the measured accuracy and adding a confidence level to the installation and the measurement. These subroutines include calculations that compare the actual process speed of sound with the process' theoretical speed of sound that was entered during set up. A perfect match is a reading of 100% which is theoretically a 0% uncertainty for the velocity measurement under the conditions entered at setup. Normally, a reading ranging from 98% to 102% indicates acceptable results within specified tolerances. Another indicator is the signal strength measurement displayed for each transducer. This will provide an indication of the acoustic coupling (linkage) of each transducer to the pipe. Another common indication is overall signal quality measurement that indicates the ratio of ultrasonic chords received to the number of chords transmitted. This ratio is expressed as a per cent and can be an indication of both the suitability of the application and the integrity of the installation. In the case of permanent mount meters with clamp-on transducers, if the field conditions have been precisely related to a flow lab, they may be able to replicate the conditions to ensure a very reasonable uncertainty. Careful installation, paying particular attention to the acoustic coupling of the transducers to the pipe wall and pipe parameters will help ensure a successful installation. The pipe wall exterior should be smooth and paint and rust free. Adequate acoustic couplant (Ultrasonic grease) should be used to link the transducers to the pipe wall and in the case of permanent mount clamp-on transducers an approved sealant around the edges of the transducer is required to avoid couplant loss or drying during the life of the installation.

Permanent Mount TOF Instruments with Integral Pipe Section (Spool Piece) and Wetted Transducers

The greatest benefit of meters with fixed mount transducers is that they can be calibrated for a specific application in a certified flow facility by the manufacturer and/or sent out by the user for periodic re-calibration checks during the meter's lifetime. This re-affirms the published precision error spec and eliminates almost all systematic errors. Manufacturer's accuracy statements of fixed mount transit time meters with integral transducers and remote or integrally mounted transmitters range from < 1.0% (R) to 2% (R) with a 60:1 turndown to <0.5% (R) to 1.0% (R) with a certified calibration. These meters are available two versions, single path and multipath the selection of which is based on the process application.

Liquid applications are often single path instruments. Exceptions to this are custody transfer applications and large pipes. In large, full pipes generally larger than 1m(40") the transducers are precisely positioned manually inside the pipe. The two methods of precisely installing transducers inside a pipe are: 1/ using a tape measure or 2/ using a surveyor's Theodolite. (See reference #3). The exact angle of the transducer's position within the pipe and the pipe's roundness are also critical factors for reducing the Systematic error component of the uncertainty. It is also important to note that internally mounted transducers may contribute to the integration error of the system by their potential to disturb the flow profile.

Gas applications are almost always multipath and used for custody transfer. Multipath meters for gas can feature 3,4 and 5 or more paths. The transducers paths do not pass through the center of the pipe but instead the transducers are carefully mounted so that the paths are off center and travel in rectangular or circular cross-sections around and within the pipe. The electronics integrates the resulting velocity measurements with the pipe area to calculate total flow. (See References 1, 4, 5, & 6).

B) DOPPLER ULTRASONIC FLOW METERS

Portable & Clamp-on Doppler Instruments

The accuracy statement of Doppler principle flow meters is +/-2% (R) or (FS) on a turndown of 60:1with a repeatability of 0.1 to 0.2% (R) for both portable and fixed mount. This is the precision error component of the uncertainty and similar to transit time meters described earlier, factors to consider that may affect the installation's integrity and resultant overall flow measurement accuracy include: the pipe's outside surface, a lined pipe, the bonding of the liner to the pipe (see linkage), a coating or build up in the pipe, pipe eccentricity, pipe wall surface, pipe roundness or ovality, pipe material, environmental factors and flow profile.

The Doppler Flow meter relies on reflectors in the flow stream to reflect the ultrasonic energy. As a result, there is a lower limit for the concentration and size of solids or bubbles in the liquid that will give a reliable, accurate measurement. The flow also must be fast enough to keep the solids in suspension or the bubbles moving. This is typically at velocities of 1.8 m/s (6 ft/s) minimum for solids and 0.75 m/s (2.5 ft/s) minimum for small bubbles.

In the past few years, some manufacturers have introduced flow meters that operate at frequencies of 1 MHz or higher. These high-frequency units are supposed to allow the meter to operate on virtually clean liquids because reflections will occur off the swirls and eddy in the flow stream, however, it is advisable to be aware that high-frequencies tend to rapidly attenuate in higher concentrations of bubbles or particles (> 0.05%) and that causes the beam penetration depth to be much lower. For reliable operation, a high-frequency Doppler flow meter should be limited to very low particulate concentration applications and smaller pipes.

C) HYBRID ULTRASONIC FLOWMETERS

The recent introduction of hybrid ultrasonic meters to the market holds potential for applications that were previously off limits to either Transit Time or Doppler meters. These meters feature both TOF and Doppler technologies resident in the same transmitter and using the same transducers. Changing from one configuration to the other is accomplished using a switch/digital input. Future developments suggest that this may become an automatic feature. The accuracies of +/- 2 - 5% (R) with a 50:1 turndown for this meter are the norm depending on the mode. This can be improved to +/- 0.5% (R) to +/- 1% (R) in the TOF mode and +/-2% (R) in the Doppler mode with a certified calibration.

D) OPEN CHANNEL - TIME OF FLIGHT/PULSED DOPPLER, ACOUSTIC DISCHARGE FLOWMETERS

The on-going concern and interest in the environment and the need for reliable, cost effective open channel flow metering has spawned tremendous growth in the field of open channel measuring devices. Applications include: measuring and monitoring water management systems, storm water run-off, irrigation flows, electric-hydro generating penstocks and industrial outfalls.

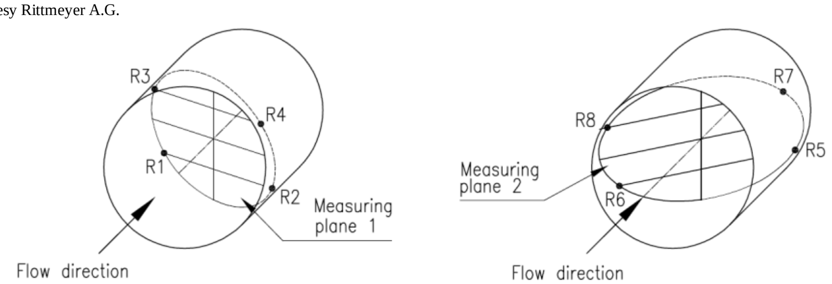
The total channel flow or acoustic discharge as explained prior combines the flowing waterways velocity profile, level and cross-sectional profile. The two methods of accomplishing the velocity measurement are Time of Flight (TOF) and Pulsed Doppler. The level is measured hydrostatically, by ultra sound/sonar or manually.

1/ TOF Systems: In straight forward applications, (one way channel flows, very regular geometric shaped conduits etc.) TOF systems are used. The system's transducers are precisely installed on either side of the channel at matching levels in the channel. Simultaneously, a level measurement (hydrostatic or ultrasonic) is continuously taken and then integrated with the velocity measurements to produce the flow total (called Stage Discharge). Up to 4 paths or more are simultaneously monitored. This technology can be used on channel widths to 100m (310ft) and closed conduits up to 20m (62ft) in diameter. (Figure 26.4) Typical uncertainties on properly installed and maintained systems are > +/-0.5 % (R) but proper installation is critical.

2/ Pulsed Doppler Systems: In applications where complex flow patterns are involved (variable backwater, tidal flow, bi-directional flow, rapid changes, irregular shaped channels or river beds, etc.) The de facto standard is to use the velocity-index technique. This involves installing up-looking or side-looking pulsed Doppler transducers mounted at the bottom or side of the channel/river (see Reference #10). The transducers pulse multiple chords upstream and tracks the velocity profile across a cross-sectional profile of the channel through the reflected waves. (See Figure 26.5) At the same time a transducer measures the channel's depth. Prior to these measurements a very accurate cross-sectional profile of the specific section of the channel is made. All this information is combined to produce a consistent and highly reliable discharge (flow) measurement with minimal systematic error.

This style of meter is also available as a handheld portable instrument, a larger transportable unit (meant for temporary unattended operation and easily re-purposed, or a boat mounted instrument. The handheld configuration of this instrument requires the user to enter the river or channel to perform hand-on, real-time measurements. The transportable units are often installed in locations to acquire data for studies then re-deployed. Boat mounted configurations are on a boat that traverses the channel or river and simultaneously uses sonar to measure channel depth. While tracking the boat's position laterally on the river a sub-surface pulsed Doppler measures velocity. All the data is stored and processed to provide a detailed flow profile of the area under study. Alternatively, the same equipment may be mounted on a dolly that traverses the river on a cable strung across the flow stream at the point of measurement.

Figure 26.4
Courtesy Rittmeyer A.G.



Graphical representation of multipath TOF measuring system in a large conduit

Figure 26.5
Courtesy SonTek/YSI, Inc. USA

Actual picture of open channel acoustic discharge Doppler meter with close-up graphic depicting operation

INSTALLATION GUIDELINES

Any flow meter's performance can be negatively affected by a poor installation. Likewise, certain types of ultrasonic meters are more sensitive than others to installation parameters. Listed below are some guidelines to help ensure the successful installation of ultrasonic meters
.

1. Ensure the process fluid meets the requirements of the metering technology
2. Protect the transmitter from environmental influences (cold, sun, moisture, etc.)
3. Do not run transducers signal wiring near electrical transmission wires
4. Mount the transducers with 10 to 20 diameters of straight pipe upstream and 5 diameters downstream
5. Ensure a full pipe
6. Ensure metallurgical compatibility
7. Ensure pressure and temperature limits are not exceeded
8. Know and re-confirm the pipe data (material, wall thickness, ID, OD etc.) and process details.
9. Confirm that the correct data is entered into the meter where applicable
10. Ensure a smooth clean external pipe wall for clamp-on transducers
11. On horizontal pipes, the best place to locate the transducer around the circumference should be determined on the basis of empirical testing and application experience (avoid the 12:00 & 6:00 o'clock positions)
12. On vertical pipes, the flow should be going up
13. Ensure that clamp-on transducers are properly acoustically coupled
14. Ensure that clamp-on transducers in permanent mount location are securely affixed and properly sealed
15. On larger pipes check ovality
16. Confirm transducer mounting distances and angles
17. Properly train installation and operating personnel

HARDWARE

TRANSMITTERS, DISPLAYS, AND INTELLIGENT UNITS

The Ultrasonic flow meter's transmitter/electronics can be mounted either on the pipe section beside the transducers or remotely mounted and connected to the transducers via cable. The application/process conditions usually dictate the transmitter's mounting location. Transmitters currently available provide a wide array of outputs including 4-20-mA DC, analog low voltage, sinking or sourcing digital pulses and contact closure outputs or inputs. The latest electronics (transmitters) sample at rates up to 1000 samples/second for signal averaging. In addition some transmitters can perform flow corrections and uncertainty adjustments on the measured velocity. In addition several meters incorporate temperature and pressure inputs to calculate thermal efficiencies, thermal loss, BTU content and mass flow. Most transmitters can then output this information or store it in an internal data logger. The on-board LCD displays in addition being used to program, provide instantaneous flow rates (forward and reverse) and have forward/reverse/net flow totalizers. Most transmitters have some form of indication of alarm statuses (i.e. hi, lo), overall system operation (i.e. health) and some form of accessibility to the values of the non-flow external inputs (pressure, temperature etc.). Common communications software protocols include Modbus, BACnet, Profibus and HART. Communication hardware connections include USB, RS-485, SDI-12 and RS-232. "Intelligent" flow meters being developed are capable of distinguishing between flow resulting from true process reflector movement as opposed to vibrating stationary particles or air bubbles that erroneously indicate flow when there is none. Some transmitters can be programmed to use any manufacturer's transducers including allowing the user to provide their own transducers with built in angle compensation for transducer mounting in unique applications.

TRANSDUCERS

Many of the process applications listed below, have been made possible by improvements in the processing speed and functionality of the transmitter and developments in the design of the companion ultrasonic transducers. Most Time of Flight and Doppler meters have used longitudinal wave ultrasonic signals to perform an accurate, reliable and repeatable measurement on many standard measurements. Recently introduced transducers use Lamb Wave or Shear Wave ultrasonic signals to successfully address challenging applications (See Reference #11). Lamb waves are wide beam transmissions of a frequency in tune with the harmonics of the pipe. These types of transducers work well on gases at lower pressures with standard pipe wall thicknesses. Shear Wave type transducers transmit a narrow focused beam with the sound vibrations perpendicular to the direction of the beam itself. This allows ultrasonic meters to measure high pressure gases in thick walled pipes.

In other developments, there are transducers that also measure the process temperature to allow the transmitter to adjust the speed of sound as the temperature changes reducing bias error.

Now available on the market are clamp-on meters that can measure the thickness of the pipe wall to ensure a more accurate set-up and therefore improved accuracy.

Finally, there are ultrasonic transducers available with a concave pipe interface surface that facilitates easier mounting and positioning on small diameter pipes (<1" / 25mm).

NEW DEVELOPMENTS

APPLICATIONS

Several important developments now allow ultra sonic flow measurement to address important, new process applications. Ultrasonic flow meters for use in custody transfer of natural gas have become very large growth areas. This started in Europe in 1995, when Groupe Europeen de Recherches GaziSres (GERG) approved the use of multipath ultrasonic flow meters for this application. The market sharply expanded when, in 1998, the American Gas Association (AGA) using independent criteria, produced the AGA9 Standard for applying Ultrasonic meters to custody transfer applications. A new TOF type Ultrasonic Meter has been introduced specifically for custody transfer measurement of cryogenic fluid processes (See Reference 7). This allows Ultrasonic meters to be used in the burgeoning field of LNG (liquid natural gas) production. These meters are 8 path devices with an operating temperature range from -196°C to +60°C. (see Figure 26.6 below) Ultrasonic flow meters have been recently introduced that can measure the methane content of metered multi-component biogas by measuring the sound velocity, temperature and chemical composition of the process. If two of the three are known then the third can be calculated (See Reference 8). Another development in the field of Ultrasonic gas measurement, has resulted in meters that can determine gas pipeline silting. Such a built-up could result in integration errors contributing to the overall systematic error. There is a meter, available for both gas and liquids applications featuring clamp-on transducers that, when flow calibrated, will produce custody transfer quality measurements. (See Reference #13).

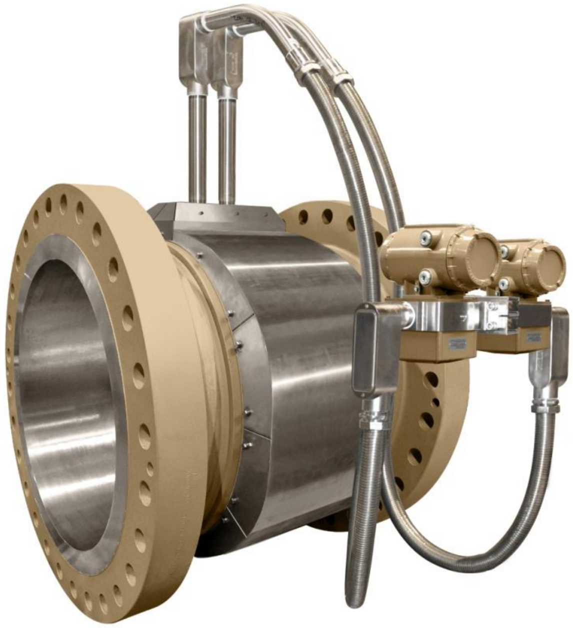


Figure 26.6

Courtesy of Emerson/Daniel Measurement and Control, Inc.

INTERNET SEARCH WORDS:

Transit time ultrasonic flow meter; Doppler ultrasonic flow meter; Hybrid Ultrasonic flow meter; Acoustic discharge meter; open channel flow measurement; measurement uncertainty; USGS flow; AGA9; Lamb Wave; Shear Wave

REFERENCES & NOTES:

1. AGA Report No. 9 specifies calibration flow rates of: 0.0, 0.025qmax, 0.05qmax, 0.10qmax, 0.25qmax, 0.50qmax, 0.75qmax, and qmax., where q = maximum calibrated flow rate, as necessary turn-down for custody transfer calibrations in gas
   http://freepdfdb.org/pdf/aga-report-9
2. A detailed review of Measurement Uncertainty is beyond the scope of this chapter. An in-depth explanation of the intricacies of Measurement Uncertainty calculations can be studied in R. Dieck's book: Measurement Uncertainty - Methods and Applications, an independent learning module published by the International Society of Automation
   www.isa.org
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