Badger Meter

Ultrasonic Metering for Small Water Meter Applications

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White Paper

Table of Contents

Summary

For many years, ultrasonic metering has been utilized for large scale liquid and gas measurement. However, it is a relatively new technology for small meter applications – particularly those designed for potable water. This paper outlines ultrasonic metering operating principles and the use of this technology by utilities in small water meter applications. Also included is a discussion regarding the Badger Meter E-Series® Ultrasonic meter and its suitability for these applications.

Introduction

Mechanical meters have been used in the water industry for more than 150 years. In recent years, a number of electronic metering technologies have emerged. One of these advancements, the ultrasonic flow meter, was initially introduced in the early 1960s for industrial applications.

Historically used for custody transfer involving natural gas and hydrocarbons, ultrasonic meters are now found in a wide range of applications encompassing dirty liquids, chemicals, and liquids with entrained particles. More recent applications include steam and clean water.

To date, water utilities have used ultrasonic meters primarily for large volume applications including raw water, water treatment and water custody transfer. Ultrasonic meters have gained acceptance in large metering applications due to several advantages over traditional measurement technologies:

- Wide measuring range or turndown
- High accuracy sustained over the meter's life
- High repeatability
- No moving parts to wear out or to generate noise
- Minimal intrusion in the flow stream
- Negligible pressure drop
- Generally unaffected by particles in the water
- Bidirectional by design
- Minimal maintenance

In general, these same advantages apply to small ultrasonic water meters when compared to positive displacement meters. However, in the past, using ultrasonic technology for small applications was viewed as impractical and/or cost-prohibitive.

Today's technological advancements make the use of ultrasonic technology feasible for small metering applications. In particular, improved high-speed digital signal processing, advanced piezoceramic transducers and sophisticated computer technology make ultrasonic flow meters a viable, cost-effective option.

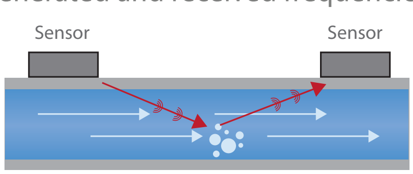
Understanding Ultrasonic Flow Meter Technology

An ultrasonic flow meter is an inferential meter that uses ultrasonic technology to measure the velocity of an acoustically conductive liquid or gas moving through it. There are two types of ultrasonic flow meter technologies: Doppler and transit-time.

Doppler Ultrasonic Flow Meters

Doppler ultrasonic flow meters are designed to measure the flow of liquids that contain suspended particles or "reflecting particles." To ensure accurate measurement, particles of a sufficient number and size must be in the medium on a continuing basis. Therefore, these meters are normally used with dirty liquids.

Typically, the meters position a pair of transducers opposite each other, across the pipe but can be mounted on the same side of the pipe. One transducer sends an acoustic pulse or sound wave, which is then reflected off the particles traveling in the flow stream. These particles are traveling at the same speed as the flow. As the signal passes through the stream, its frequency shifts in proportion to the mean velocity of the fluid. The other transducer receives the reflected signal and measures its frequency. The meter calculates flow by comparing the generated and received frequencies.



Doppler Shift

Doppler Principle: Ultrasonic signals are reflected off particles moving downstream. The frequency differential increases as flow increases

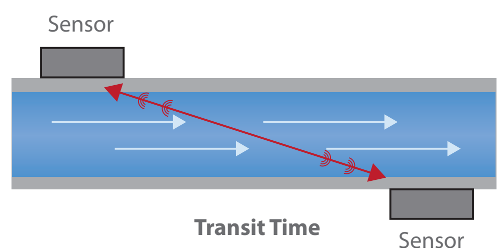
Transit-Time Ultrasonic Flow Meters

Initially used only for clean liquids, transit-time meters can now accurately measure flow in a wide range of fluids, thanks to dramatic improvements in signal processing technology over the past 20 years. Transit-time meters are now one of the most universally applied flow metering methods – and one of the most accurate.

Transit-time technology takes advantage of the principle that an acoustic pulse travels faster with the flow than against the flow. These meters have a pair of transducers, which act as both sender and receiver. The transducer on the upstream side of the meter generates an acoustic signal that travels through the pipe along a predetermined path. The downstream transducer receives the signal, and the meter calculates how long it took to travel from the one transducer to the other. Next, the downstream transducer generates a signal that travels upstream along the same predetermined path. This signal is received by the upstream transducer, and the meter calculates how long it took to travel in the upstream direction.

The difference between the downstream and upstream transit time is proportional to the flow rate.

Transit-time Principle: Ultrasonic signals are sent downstream, then upstream – and measured. The time differential increases as flow increases



Transducer Mounting Configurations

Both Doppler and transit-time meters may be designed as insertion meters, with wetted transducers located within the flow tube, or clamp-on meters, with the transducers mounted on the outside surface of the pipe.

Clamp-on meters, also called non-intrusive meters, are easy to install on existing pipes and can be particularly ideal when toxic, corrosive or sterile media is involved. However, clamp-on configurations require knowledge of the pipe diameter and thickness to operate correctly since the ultrasonic signal has to travel through the pipe wall.

In addition, Doppler clamp-on meters are subject to interference from the pipe wall itself, as well as from any air space between the sensor and the wall. Cracked or glazed pipe, steel pipe with grain regions and uncured pipe coating can be significant enough to either completely scatter the transmitted signal or attenuate the return signal. This can dramatically decrease meter accuracy. Insertion meters with wetted transducers overcome many of these signal attenuation limitations, since the transducers are permanently mounted in the flow tube and are in direct contact with the liquid or gas.

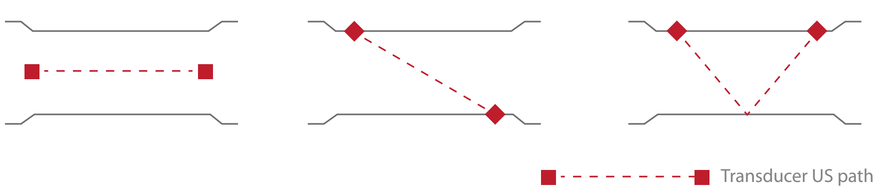
Single- and Multi-Path Designs

As noted above, the design of an ultrasonic meter involves positioning one or more pairs of transducers and precisely determining the path between the two. Transit-time meters may have a single pair of transducers (each sending and receiving ultrasonic signals) or may have multiple pairs of transducers. In either case, each transducer alternates in its function as sender and receiver.

Single-path ultrasonic meters have a single pair of transducers that takes a single path velocity measurement. To compute the flow rate, the meter typically uses a calibration table that is:

- Based on a specified velocity range and temperature range.
- Accounts for variations in the velocity profile and for flow section construction/pipe irregularities.

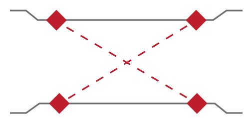
Only in unusual situations does the effect of pressure on ultrasonic signals need to be considered.



Single path designs can utilize either a direct (axial) path or a reflective path and are ideally suited for smaller pipe sizes and volumes

In multi-path flow meters, several sets of transducers are placed in different paths across the flow section in an attempt to measure the velocity profile across the entire cross-section of the pipe. Flow rate is determined by averaging the values provided by the different transducer pairs. Multiple transducer pairs are typically used with larger pipe sizes and in applications where extremely high accuracy is required. Calibration tables similar to the single-path meter tables are used.

Multi-path meters are used with larger pipe sizes and where extremely high accuracy is required



The Nature of Ultrasonic Signals and Transducers

Ultrasonic vibrations are sound waves that have a frequency higher than human hearing. In ultrasonic flow meters, these sound waves are generated by applying a small voltage to the piezoelectric transducer in the meter. The opposite also occurs: an ultrasonic signal received by the transducer is converted to an electrical signal.

The transducer is simply a device that converts one type of energy to another. In this case, it converts the electrical energy to acoustical energy and vice versa. The actual frequency of the ultrasonic signal is determined by the characteristics of the transducer used in the specific application.

The ultrasonic signal propagates at the speed of sound. But the speed of sound is variable and depends on the medium through which it is traveling and the temperature of that medium. Therefore, ultrasonic meters are calibrated for a specific liquid or gas and temperature range. Ultrasonic meters that are compatible with a variety of liquids or gases must be adjusted if the medium is changed.

Ultrasonic Speeds (Approximate) in Various Media

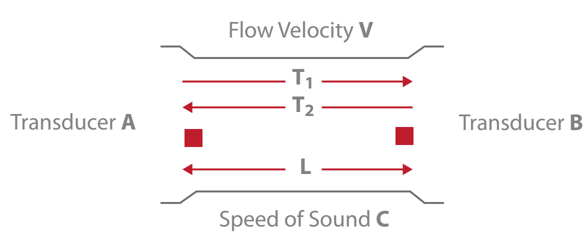
	Material	Speed (feet/sec)
Gases	Air (0°C)	1085
	Air (20°C)	1125
	Air (40°C)	1164
	Methane (0°C)	4219
	Hydrogen (0°C)	4219
Liquids	Water (0°C)	4599
	Water (20°C)	4862
	Water (25°C)	4898
	Sea Water (25°C)	5029
	Glycerol (25°C)	6246

Examples of speed of sound in various media. Speed increases with the temperature of the gas or liquid.

Transit-Time Measuring Principle

The transit-time measuring principle is simply illustrated with this example: A person in a canoe paddling downriver needs less time to travel a certain distance than a person paddling upriver the same distance. The difference between the downriver and upriver travel times depends on the strength or speed of the river current. The stronger the current, the greater the time difference.

This principle is utilized by ultrasonic flow meters to determine flow velocity and volumetric flow rate. The transit-time of the ultrasonic signal is measured between the two transducers – one upstream and one downstream. The difference in elapsed time determines the fluid velocity.



Examples of transit-time measuring principle

Variables:

T1 = Time for signal to travel downstream from Transducer A to Transducer B

T2 = Time for signal to travel upstream from Transducer B to Transducer A

L = Path length between the two transducers

C = Speed of sound in water (approximately 4862 ft/sec at 20°C)

V = Velocity of the water in the meter tube

*Basic formula for determining fluid velocity in a single path ultrasonic meter:

$$T1 = \frac{L}{(C + V)} \qquad T2 = \frac{L}{(C - V)}$$

By rearranging the terms and subtracting the second equation from the first, the velocity of the fluid can be determined:

$$V = \frac{(T2 - T1)}{(T1 \times T2)} \times \frac{L}{2}$$

Once the velocity (V) is known, the volumetric flow rate is calculated by multiplying the velocity times the cross-sectional area of the meter flow tube.

Using the basic formula shown above and a hypothetical metering situation, flow velocity can be calculated knowing the path length and transit times

Example of Transit-Time Ultrasonic Water Meter

Path length (L)	4 inches (0.333 ft)
Speed of sound in water at 20°C (C)	4862 ft/sec
Transit time downstream (T1)	68.41748 microseconds
Transit time upstream (T2)	68.69950 microseconds
Transit time difference (T2-T1)	282 nanoseconds
Flow velocity of water (V)	10 ft/sec

*Formula assumes the signal travels in a straight path. If the straight line path is across the meter at an angle or reflected one or more times, a more complex geometric formula is used to determine the signal path length.

Badger Meter E-Series Meter

The Badger Meter E-Series Ultrasonic insertion meter is a transit-time ultrasonic flow meter with wetted transducers. Designed as an alternative for small mechanical positive-displacement meters, the Ultrasonic meter utilizes traditional utility pipe connections and lay lengths. It is totally self-contained – the battery, processor circuit and electronic display are fully potted and permanently sealed as an integral unit. The Ultrasonic meter provides an output signal to AMR/AMI endpoints.

Meter Basics

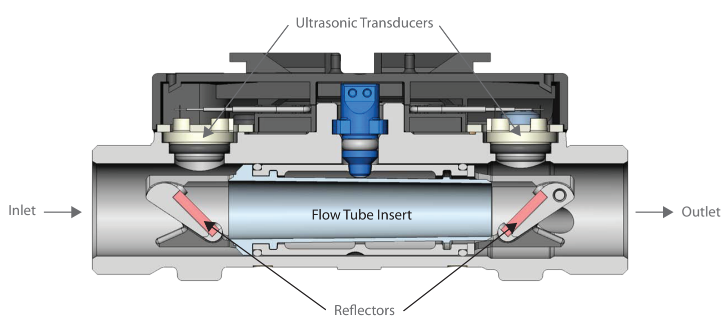
Fluid Compatibility

The E-Series Ultrasonic meter is designed and calibrated for potable and reclaimed water across a defined temperature and velocity range. Since the speed of sound varies depending on fluid density and temperature (see chart p. 8), this meter is not designed to accurately measure liquids other than water or outside the specific temperature range.

Flow Tube

The meter housing includes the straight flow tube, which contains the wetted elements of the meter: two transducers, the temperature sensor, and the metering insert, which holds two stainless steel ultrasonic reflectors.

Inferential meters typically require some straight pipe ahead and after the measurement area to act as a flow conditioner. The lay length of this small meter provides some of this functionality. In addition, the metering insert conditions the flow to minimize turbulence, distortion and swirl. Due to the swirl-free flow, chemical buildup on the reflectors is virtually eliminated.



Cross-sectional view of meter showing location of flow tube, transducers and signal reflectors

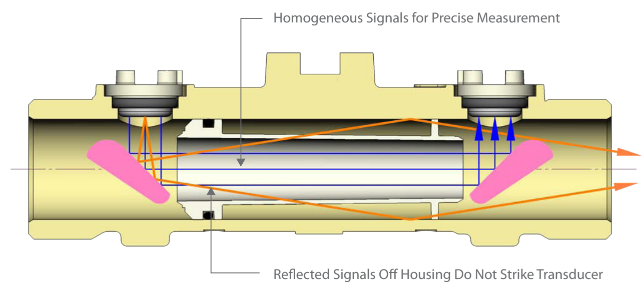
Ultrasonic signal path between the transducer pair

Transducers

The piezoelectric transducer pair is the heart of the system. Although these transducers are very small, they have very high measurement dynamics. The transducers generate a 1 MHz ultrasonic signal every second, and the timing circuits are able to measure in the nanosecond range. Keep in mind, acoustic signals in 20°C water travel at 4862 feet/second or more than 3000 miles/hour (see chart, p. 8).

The signal path utilizes two stainless steel reflectors located in the center of the flow tube (supported by the meter insert). The patented free-beam design prevents any signal reflections off the meter housing from striking the receiving transducer. Only signals that travel down the center of the flow tube are received, resulting in a homogenous sound field for precise measurement.

The transducers are permanently installed and the path length and angles are fixed. Each meter is factory calibrated based on the "as-built" conditions. The calibration data is permanently stored in the meter.



The electronic circuitry triggers the transducers, which generate and receive ultrasonic signals. In addition, the circuitry provides highly accurate time measurements through the use of complex pulse detection algorithms and digital signal processing.

Battery

A mechanical meter has one obvious advantage when compared to an electronic meter: no electrical power is required. However, with the continued development of batteries offering higher capacity, smaller size and longer life, electronic metering utilizing internal batteries is practical today. The battery used in the E-Series Ultrasonic meter is the same style used in modern Automatic Meter Reading (AMR) endpoints.

These highly reliable lithium thionyl chloride batteries are designed for a 20-year life and provide the power to operate the meter circuitry and display – and generate the ultrasonic pulses.

Installation and Application Considerations

Flow Conditioning

To optimize the performance of any inferential meter, the minimum standard industry recommendation of 5 pipe diameters of straight pipe upstream from the meter and 2 pipe diameters downstream is recommended wherever possible. This allows for dampening of velocity profile distortions caused by elbows, pumps, dirt traps, etc., prior to the meter. Where spiral flows are created by three dimensional elbows or rotary pumps, additional distance to dampen the effect is beneficial.

As noted previously, the lay length of the E-Series Ultrasonic meter housing, along with the insert in the meter housing, provides some flow conditioning.

Acoustic Noise

Acoustic noise can pose a problem for many large industrial ultrasonic meters. The ultrasonic signal these meters transmit is generally in the 100-300 KHz range, which is often the same frequency as acoustic noise generated by compressors, pumps, valves, or extreme water turbulence. Since acoustic noise in the same range as the ultrasonic signal can interfere with that signal, the noise source must be eliminated, filtered or located downstream of the meter.

This type of acoustic interference is not an issue when installing the E-Series Ultrasonic meter. The Ultrasonic meter uses a 1 MHz signal frequency, which is well above any acoustic noise that might exist in a water system.

Particulates

Fine particulates, including sand, pose problems for mechanical water meters in many utility systems. The fine particulates wear on the mechanical meter's parts, which affects accuracy over time. To counter this to some degree, mechanical meters include a screen on the inlet side to filter the particles. In larger meters, strainers are often incorporated. Even then, the microscopic particles can enter the meter and cause wear.

The E-Series Ultrasonic meter intrinsically eliminates many concerns regarding particulates. The meter's flow tube is relatively unobstructed except for the insert holding the ultrasonic reflectors. In addition, its all-electronic construction means there are no moving parts to be affected by small particles. Therefore, a filter or strainer is not needed.

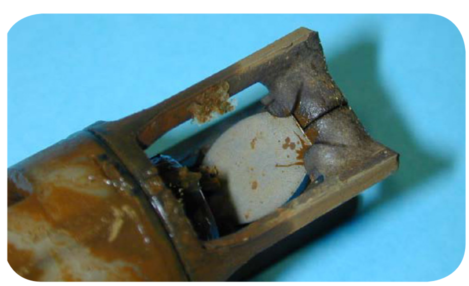
However, it's important to note that large rocks and debris might partially or completely block the flow of water in any type of meter. In addition, partial obstructions that cause turbulence in the flow stream can affect any inferential meter's accuracy. If the flow is completely blocked, an ultrasonic meter will register no flow.

Water Quality

The overall water quality within a utility distribution system can also affect the long-time accuracy of any meter. Certain chemicals may coat the meter's inner surfaces and degrade performance over time.

Although the E-Series Ultrasonic meter is less susceptible to the effects of chemical buildup due to its open flow tube design, buildup on the meter insert can gradually reduce the cross-sectional area of the insert and cause a slight shift in accuracy. However, given the insert design and flow velocity, buildup on the insert is extremely rare.

Chemicals can also build-up on ultrasonic reflectors. Theoretically, if the buildup reaches a certain point, it might absorb the ultrasonic signal, or reduce its strength enough that the signal is too weak to be detected. However, due to the design of the Ultrasonic meter's flow tube, the reflectors remain free of deposits. The photo below was taken after accelerated testing with extremely harsh water, including rust. It shows a virtually clean stainless steel reflector.



A reflector after accelerated testing of extremely harsh water, including rust, shows a virtually clean stainless steel reflector.

Water Temperature

The temperature range of the water is a factor in the selection of an ultrasonic meter, since the meter is calibrated to operate within a specified range. The E-Series Ultrasonic meter is calibrated for cold water (1°C to 60°C) measuring applications. The meter monitors water temperature and adjusts measurements to reflect the actual speed of sound at the measured temperature.

Meter Installation

The E-Series Ultrasonic meter can be installed using horizontal or vertical piping, with water flow in the up direction. While this meter uses standard lay lengths, its width and height is often less than that of mechanical meters. Because the meter is calibrated with the forward flow rate being significantly greater than the reverse flow rate, it must be installed with the forward flow being in the direction noted on the meter body. If the meter is installed backwards, the reverse flow rate maximum will likely be exceeded and measurement data will be meaningless.

Water Flow

An E-Series Ultrasonic meter is designed to sample the flow by sending ultrasonic signals at regular intervals. The Ultrasonic meter samples the downstream and upstream flow every second (sampling rate is set to balance accuracy and battery life). The meter will not measure flow when an "empty pipe" condition is detected. An empty pipe is defined as a condition when the ultrasonic sensors are not fully submerged. In this situation the meter will display an alarm and the last known good read until the meter senses a full pipe.

Meter Sizing/Selection

Traditional meter sizing methods apply to both electronic meters and mechanical meters. That is, the maximum flow and maximum continuous flow rate requirements should be considered when selecting a meter. Mechanical meters allow a temporary maximum flow at a rate higher than the maximum continuous flow. However, since electronic meters have no moving parts, these two specifications are identical: the maximum flow rate is also the maximum continuous flow rate.

The E-Series Ultrasonic meter features a wider measuring span as compared to a positive displacement meter, including both a lower extended low-flow rate and a higher maximum continuous flow rate.

If the maximum flow rate is exceeded in a mechanical meter, the meter will mechanically fail at some point. If the maximum flow rate is exceeded in an electronic meter like the Ultrasonic meter, an error will be displayed and no additional consumption will be recorded until the flow rate is back within the specified operating range.

Pipe diameter and meter connection choices are the same for Badger Meter mechanical positive displacement and ultrasonic meters.

Minimum Flow Rates

The minimum flow rate of the E-Series Ultrasonic meter is nearly identical to the mechanical meters from Badger Meter. With mechanical meters, a minimum forward water flow is needed to achieve accurate measurement. In other words, the mechanical parts must achieve a certain level of "forward momentum" with flow to measure accurately.

Since the Ultrasonic meter measures both forward and reverse flow, the minimum flow rate helps prevent quick, consecutive forward and reverse flow changes that could result in "sloshing" water in the measuring area.

Maintenance

The E-Series Ultrasonic meter does not have moving parts and requires no maintenance. The meter enclosure, which containes the electronics, transducers, battery and display, is completely potted and permanently sealed, eliminating any mainteneance. At the end of its twenty year life, the meter is simply replaced.

Conclusion

While mechanical meters are predominant in small water meter applications, recent technological advancements are helping ultrasonic flow meters make inroads into that market. Specifically, transit-time ultrasonic meters can be an ideal solution for any utility application requiring long-term measurement accuracy. Historically used for clean, potable water, ultrasonic meters such as the Badger Meter E-Series Ultrasonic meter are also ideal for ideal for non-potable and reclaimed applications – or less than optimum water conditions where small particulates exist. The meter's wide rangeability and robust operating characteristics make it an attractive choice for a utility's small metering needs.

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