Part 2: Ultrasonic

Core Technology White Paper Series

Advanced Transit-Time Measurement Technology

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About This Series:

The Core Technology White Paper Series is a four part series detailing the flow technologies that allow Sierra to offer a flow solution for nearly any gas, liquid and steam application. Part 1 focuses on Sierra's two types of thermal mass flow technologies for gas mass flow measurement and control—Capillary Thermal & Immersible Thermal. Part 2 will focus on our Transit-Time Ultrasonic for liquids, Part 3 focuses on Multivariable Mass Vortex for gas, liquid and steam, and Part 4 will detail our Primary Standard Gas Flow Calibration technologies.

Advanced Transit-Time Measurement Technology

Since the introduction of ultrasonic transit-time flow meters, manufacturers have continually improved their measurement and signal processing capabilities. Recent advances in digital correlation transit-time technology allow customers to use this convenient, non-intrusive installation to address some of the more challenging flow applications.

Ultrasonic flow meters are divided into two measurement technologies: ***Doppler & transit-time***. These technologies are available in two styles: 1) clamp-on (non-intrusive to the piping system) or 2) wetted (inserted into the pipe with the sensors exposed to the flowing fluid).

Traditionally, magnetic flow meters have been used in water and waste water applications. If ultrasonic flow meters were used at all they were typically based on Doppler technology. However, with advances in signal processing and more powerful transducers, transit-time technology has far surpassed earlier predecessors in measuring these commonly “dirty” flows.

This paper focuses on the unique capabilities of transit-time ultrasonic flow measurement technology and explains how recent advances have allowed this technology to be used in the toughest applications.

Doppler Ultrasonic Flow Meters Explained

It is first important to discuss Doppler ultrasonic technology. In a Doppler system, two transducers transmit a pulse of acoustic energy into the flow stream, and receive a reflected echo off particulate matter carried in the stream. The frequency of this reflected signal is compared to the transmitted signal. **Figure 1** illustrates a typical Doppler ultrasonic flow meter.

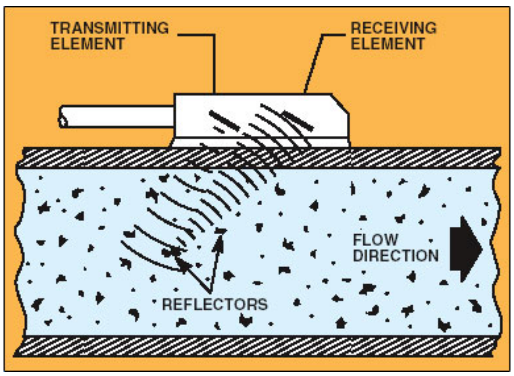

Figure 1 *Doppler Ultrasonic Flow Meter*

The frequency/velocity dependence upon which the measurement is based was discovered in 1845 by Austrian mathematician Christian Doppler, who determined that the frequency of a sound wave that is reflected off a moving object will be shifted by an amount proportional to the speed of the moving object (the analogy of the pitch of a train whistle moving up and down as the train passes is often used to illustrate this).

It is assumed that the velocity of the moving particles is the same as the fluid they are carried in. By measuring the velocity of these particles and knowing the pipe cross sectional area, the volumetric flow rate is determined. In order for the Doppler meter to operate correctly, there must be sufficient "material" in the flow stream to reflect this acoustic energy. Additionally, these materials must be moving homogenously with the flow or errors will be induced into the measurement.

In general, Doppler meters will provide an installed measured accuracy in the +/- 2 to 5% range. In all cases, they are actually measuring the speed of the particles IN the fluid which ideally will be the same as the speed of the fluid.

Transit-time Ultrasonic Flow Meters Explained

In a transit-time ultrasonic flow meter, an ultrasonic signal is transmitted in the direction of the flowing fluid (downstream), and then another signal is transmitted against the flowing fluid (upstream). This is illustrated in **Figure 2**. In its most basic form, the time for the sonic pulse to travel downstream is compared to the time for the pulse to travel upstream. This differential time is then used to calculate the velocity of the flowing fluid.

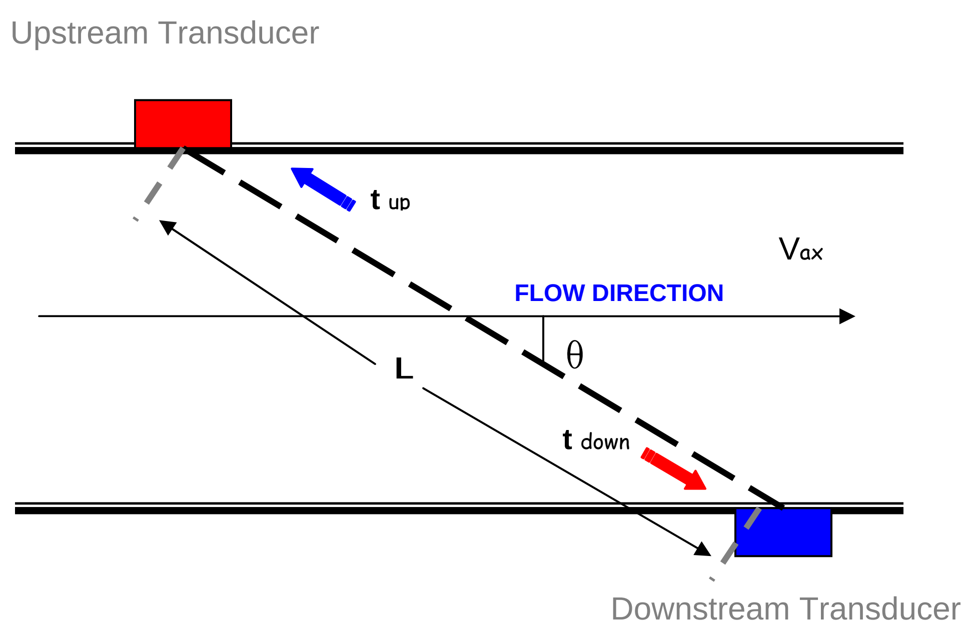

Figure 2 *Transit-time Ultrasonic Flow Meter*

When the ultrasonic signal is transmitted through the flowing liquid, there will be a difference between the upstream and downstream transit-time (time of flight or time difference), which is proportional to flow velocity. ***Equation (1)*** illustrates this:

$$V_{ax} = \frac{L}{2 \cos \Theta} \times \frac{\Delta t}{t_{up} \times t_{down}} \quad (1)$$

Where:

V_{ax} = the axial liquid velocity along the acoustic path

L = straight line distance between the centers of the faces of the upstream and downstream transducers

Θ = the path angle of transmission relative to the fluid at rest

t_{up} = the upstream transit-time

t_{down} = the downstream transit-time

$\Delta t = (t_{up} - t_{down})$ = the differential transit-time

Digital Correlation Transit-time Technology Explained

In today's modern digital correlation transit-time technology, the signal is typically a high frequency (1 MHz) wave that is analyzed by the microprocessor. Since the system operates at extremely high speeds, it is impractical to have an electronic clock start and stop timing in order to measure the transit-time between the sensors. Instead, these two high frequency signals are digitally plotted against each other and the phase angle of the sine wave is measured (see **Figure 3**). It is this sine wave phase shift that is the basis for the measurement.

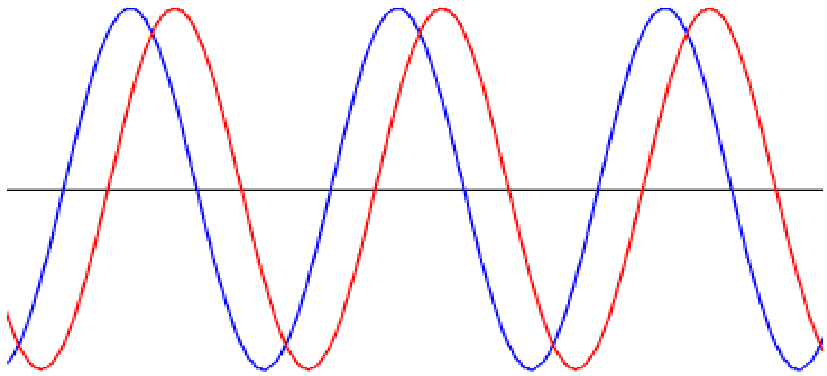

Figure 3 *Phase Shift of the Upstream and Downstream Signals*

Advances in Digital Correlation Transit-Time Technology

Next generation transit-time flow meters appearing on the market today are capable of sampling 256 samples per second, bringing the measurement resolution from nanoseconds 10^{-9} (used in the current generation of instruments) into the range of picoseconds 10^{-12}. This increased resolution capability has enabled the few advanced transit-time ultrasonic flow meters on the market today to precisely track fluid movements down to a true zero flow condition.

Transit-time solves two of the problems associated with Doppler: 1) it does not require reflective material in the flow stream and thus has wider applicability and 2) it does not make the assumption that flow is homogenous throughout the pipe.

Installation Considerations

Figure 4 illustrates field installation of the transducers where the flow is moving from right to left. This is the mounting style known as a “V”, where the sonic path travels across the pipe, is reflected by the opposite inside pipe wall and then proceeds to the downstream transducer.

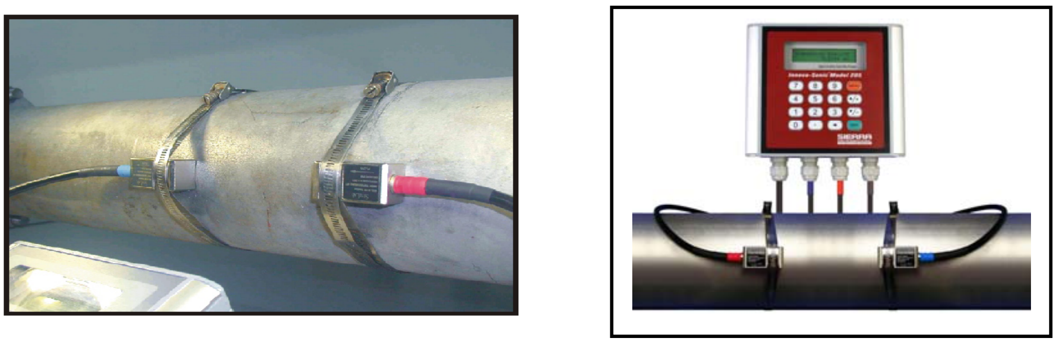

Figure 4 *Field Installation of the Transducers*

There are several different mounting styles for ultrasonic transducers which are selected based on pipe diameter, conditions of the pipe systems, and the fluid. Two of the most common mountings are shown below, the “V” Mount (**Figure 5**) and the “Z” Mount (**Figure 6**).

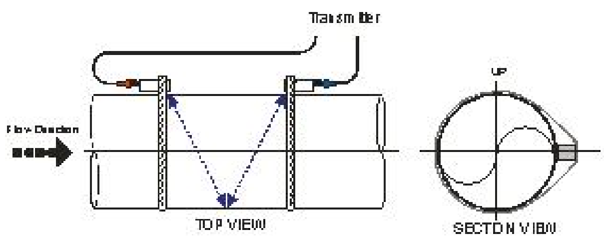

Figure 5 *“V” Mounting Configuration*

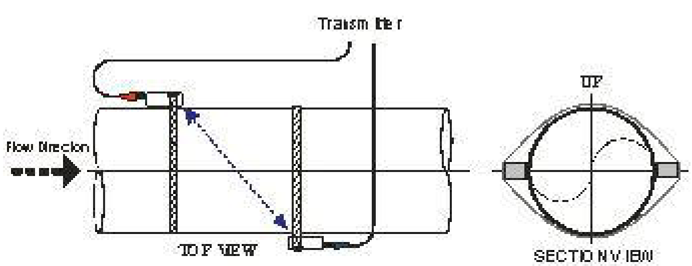

Figure 6 *“Z” Mounting Configuration*

The "Killer Applications" for Transit-time

Chilled Water and Cooling Water

Chilled water & cooling water flow measurement applications are commonly measured with some type of positive displacement instrument, such as a turbine or paddle wheel flow meter. With advances in transit-time ultrasonic flow meters, the use of ultrasonic flow meters is becoming much more common in making building chill water and process cooling water flow measurements.

The major benefits of using transit-time technology in these applications are that (1) the process does not need to be shut down for installation and (2) the meters have a much greater sensitivity to low flows. Since the transit-time measurement is not dependent on the fluid to impact sensors (the only considerations are that the pipe is full and constructed of an acoustic conducting material), the processing ability of today's clamp-on transit-time flow meters allows a much lower velocity reading closer to an actual zero flow measurement.

Municipal Water and Waste Water

Municipal water and waste water applications are using more clamp-on transit-time flow meters as advances continue. Experience has proven that in the majority of the applications (raw sewage, lift stations, sludge lines (~5% or less), plant influent, and effluent lines) ultrasonic transit-time flow meters are outshining the traditionally used magnetic flow meters or Doppler meters for the following reasons:

1) **Ease-of-Installation:** The largest benefit of the any "clamp-on" transit-time flow meter is obviously the ease-of-installation. While still requiring sections of straight pipe upstream of the measurement location, the process does not require shutting the system down to install, making maintenance and upkeep of transit-time meters much more attractive. Additionally, there is far less maintenance required. There are no blades to wear out or bearings to replace as in turbine meters, nor are there electrodes that can foul over time as in magnetic flow meters.

2) **Better Accuracy at Lower Flow Rates**: Historically, from a waste water market standpoint, ultrasonic flow meters were standardized on a Doppler technology. However, with advanced signal processing found in digital correlation transit-time meters coupled with more powerful transducers, today's transit-time units have far surpassed their earlier predecessors in measuring these commonly "dirty" flows.

Are today's transit-time ultrasonic flow meters the "universal flow meter" for every application? Probably not, just like other instruments, they have some minimum requirements for successful applications. They require full pipes, the pipe material must be acoustically conductive (no rubber hoses), and have some amount of straight run for a developed flow profile. However, if these minimum requirements can be met, for the first time, modern day transit-time instruments have the horsepower and accuracy to fit several demanding flow applications that historically would have required less accurate and more expensive methods.