Flow metering tutorial - Part 4: Ultrasonic flow meters

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[Part 1 of this series covers the fundamental concepts and principles incorporated by flow meters along with various flow measurement methods used in mechanical flow meters. Part 2 covers the pulse based counting method and the various sensors that are used in industry and the way they generate different pulse waveforms to be used in variety of flow meters. Part 3 covers the methods used to perform the measurement of the pulse waveforms in these flow metering systems.]

Ultrasonic Flow Meters: Introduction

These are the type of flow meters that measure the velocity of liquid or gas by using the principle of ultrasound or sounds waves. Fast digital signal processors and sophisticated signal analysis guarantee reliable measuring results even under difficult conditions where ultrasonic flow meters had failed previously.

Advantages over traditional meters

Unlike the traditional meters that have moving parts, ultrasonic meters do not include any moving parts and thus are more reliable, accurate and provide a maintenance free operation. With the homogenous fluids, the principle is independent of pressure, temperature, conductivity and viscosity.

Ultrasonic meters offer completely non-invasive measurement and do not need any pipe construction. Unlike the traditional meters, they don't face the issue of pressure loss.

Since ultrasonic signals can also penetrate solid materials, the transducers can be mounted onto the outside of the pipe and are usable under wide range of nominal diameters (Figure 1).
An important point to note is that ultrasonic meters are more suitable to measure non-conductive fluids.

**Ultrasonic Meters: The Theory**
Swimming against the flow requires more power and more time than swimming with the flow. Ultrasonic flow measurement is based on this elementary transit time difference effect.

Two sensors mounted on the pipe simultaneously to send and receive ultrasonic pulses. At zero flow, both sensors receive the transmitted ultrasonic wave at the same time, i.e., without transit time delay.

When the fluid is in motion, the waves of ultrasonic sound do not reach the two sensors at the same time. This measured "transit time difference" is directly proportional to the flow velocity and therefore to flow volume. By using the absolute transit times both the averaged fluid velocity and the speed of sound can be calculated.

The transducers can be mounted in reflection or in diagonal mode as shown in Figure 2.

![Figure 2: Ultrasonic Transducers mounted in Diagonal Mode and Reflect Mode](image)

**Measurement Principle: Time of Flight and Doppler**
There are two measurement principles in ultrasonic meters

a. Time of Flight or Transit-time
b. Doppler

**a) Transit Time Principle**
Flow measurement shown in Figure 2 is based on Transit time principle that utilizes two transducers, which function as both ultrasonic transmitters and receivers. The transducers are clamped to the outside of a closed pipe at a specific distance from each other (Figure 3).
The flow meter operates by alternatively transmitting and receiving ultrasonic signal pulses between the two transducers. The ultrasonic signals are first transmitted in the direction of the fluid and then against fluid flow.

Since sound energy in a moving liquid is carried faster when it travels in the direction of flow than against it, a time difference between the signals time-of-flight will occur. If the fluid is not moving, the time difference is zero and the flowmeter will indicate zero flow. The transit-time of the signals is accurately measured in both flow directions and the difference in time calculated.

\[ L = c \times dt + v \times dt \]  
\[ \text{(1)} \]

Where:
- \( L \) = distance between emitter-sensor
- \( dt \) = runtime
- \( v \) = flow velocity
- \( c \) = speed of sound

Thus,

\[ \text{Flow Velocity (v)} = \frac{(L/dt)} - c \]  
\[ \text{(2)} \]

As shown in the above equation, the time difference of the ultrasonic signals is proportional to the flow velocity in the pipe. This time difference is extremely small - for example, 30 nanoseconds (30 x 10^-9 sec) for a flow of 1 meter/sec in a 100mm pipe. In order to achieve accuracy particularly on smaller pipes with very low flows it is necessary to have a system that can resolve time differences of less than 0.5 nanosecond, and requires ultra-high-speed counters making the measurement a challenge.

The Time of Flight or transit-time technique is suitable for clean liquids (< 2% particles or contaminates) like water and can provide accuracies better than 1%.

b) Doppler Principle

Doppler principle of measurement is suitable for contaminated or aerated liquids where the solid content is pretty high (> 10% by volume) and measurement cannot be done using Time of flight method. Doppler principle actually relies on particles or gas bubbles flowing with the liquid in order to give a flow rate reading (Figure 4).
Figure 4: Measurement based on Doppler Principle

When ultrasound hits a moving particle or gas bubble, the reflected sound can be detected and the frequency shift measured. The frequency change is proportional to flow velocity which is converted to volumetric flow rate by multiplying by the cross sectional area of the pipe (Figure 5).

Figure 5: Doppler Sensors (Ultra Sonic Meters)

*Note:* This method is only used on liquids that have particles present, not for clear liquids (fluids under high pressure) and this is also the reason why Doppler sensors cannot measure flow of distilled water.

Coming up in Part 5: A typical flow metering MCU.