MULTIPATH FLOWMETER SYSTEMS
THEORY AND OPERATING PRINCIPLE

ACCUSONIC®
TECHNOLOGIES

Description

Accusonic flowmeters utilize the multiple parallel path transit time flwo measurement technique which is designed for accurate flow measurement (±0.5% of actual flowrate) in large pipes and open channels. The systems can be configured to measure flow in fully surcharged pipes and conduits, pipes and conduits ranging from partially full to surcharged (compound configuration), and open channels. Depending upon accuracy requirements, the flowmeters can be set up to operate 1-8 acoustic paths with cross path (cross flow) correctionh available on flowmeters with 2 or more paths.

A single console can be used to handle flow measurements in multiple pipes.

Theory and Operating Principle

The Accusonic flowmeter is connected via signal cables to multiple pairs of transducers mounted in a pipe or channel at specific elevations. Velocity at each elevation is determined using the differential travel time method in which an acoustic pulse travels downstream faster than a pulse travels upstream. A pulse of sound travelling diagonally across the flow in a downstream direction will be accelerated with the veloicty component of the water and, conversely, a pulse travelling diagonally upstream will be decelerated by the water velocity. This method of measurement is described as follows:

$$T1 = \frac{L}{C - V \cos \varnothing} \qquad T2 = \frac{L}{C + V \cos \varnothing}$$

Where:

T1 = Travel time of the acoustic pulse between transducer B and transducer A (Figure 1)

T2 = Travel time of the acoustic pulse between transducer A and transducer B

C = Speed of sound in water

V = Velocity of the water

Ø = Angle between the acoustic path and the direction of water flow

The above equations are solved for V, independent of C, yielding:

$$V = \frac{(T_1 - T_2)}{(T_1 T_2)} \times \frac{L}{2 \cos \varnothing}$$

Therefore, the velocity of the water at the acoustic path can be calculated by knowing the path length (L) and path angle (Ø), and measuring the time for the acoustic pulse to travel between the transducers in the upstream and downstream directions.

Typically, four pairs of transducers are spaced in the pipe or channel to give four parallel acoustic paths (see Figures 3 & 4). Velocities for these paths are then integrated so that flow is measured according to the following equations:

1. For Pipes:

$$Q = 2R^2 \sum_{i=1}^{4} w_i v_i$$

Where:

Q = Flowrate

R = Pipe radius

w_i = Integration weighting constant for the ith path (defined by the path location)

vi = Velocity determined by the ith path

i = Number of acoustic paths

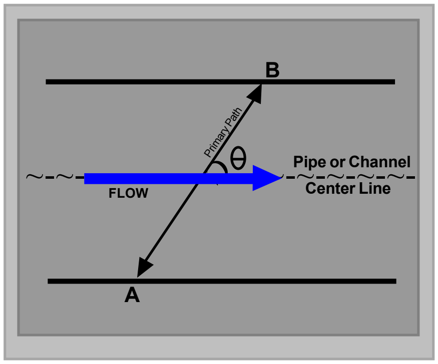

Figure 1 Acoustic Path Layout

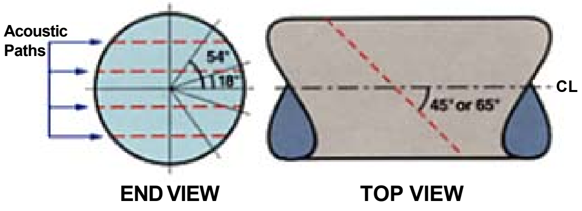

Figure 2 Typical full-pipe pipeline placement (using the Gauss-Chebyshev integration method)

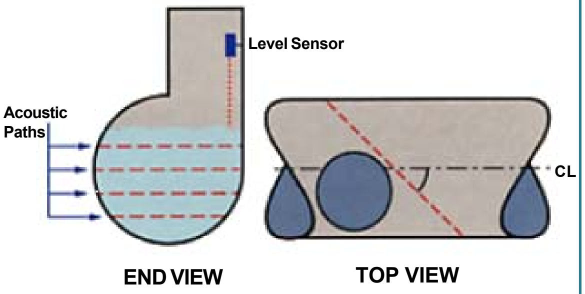

Figure 3 Typical partially full pipe

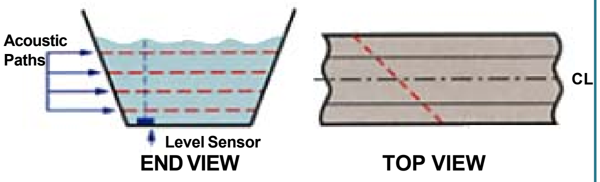

Figure 4 Typical open channel path placement

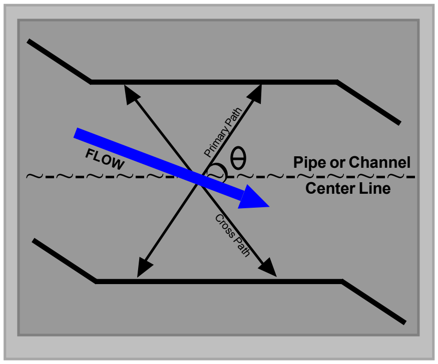

Figure 5 Cross Path Configuration

2. For open channels and partially full pipes:

When more than one path is submerged

$$Q = [A_{Bottom\,*} V_{A*}(1 + F_{Bottom}) / 2] + [\sum_{i=1}^{n} A_{i\text{-}i+1*}(V_i + V_{i+1}) / 2]$$

$$+ [A_{Top*}(V_n + W_{Top*} V_{Surface}) / 1 + W_{Top}]$$

Where:

Q = Flowrate

A = Cross sectional area (determined as a function of depth and channel/pipe dimention)

V_A = Velocity of lowest path of lowest pair of crossed paths

F_{Bottom} = FBottom friction coefficient

V_i = FVelocity of the i path or pair of crossed paths

W_{Top} = FWeight for the surface velocity to correct for friction at the surface

$V_{Surface}$ = FSurface velocity extrapolated from the top two measured path velocities

For pipes and channels where only one path is submerged:

$$Q = V * C * A$$

Where:

A = □ (depth)

C = A correction factor to correct velocity measured as a function of the path height to depth. The correction factor is based on USGS developed velocity/depth relationships.

In cases where there is a very short (less than 5 x width or diameter) straight channel or pipe run upstream of the meter section, it is likely that the direction of flow will not be parallel to the centerline. If this is the case, a second "crossed path" at each elevation will be required to eliminate the cross-flow error (Figure 5).

3. For pipes and conduits that range from partially full to surcharged:

For compound applications, Accusonic meters are designed to automatically change mode of operation from open channel to full pipe as the conduit surcharges. The method of flow calculation used is as appropriate for the depth, number of paths submerged and path locations

From the above, it can be seen that to calibrate or set up an acoustic flowmeter, all that is required is to measure the distance between the transducers, the angle of the transducers with respect to the centerline of the pipe or channel, and the physical dimensions of the pipe or channel. The multiple parallel path acoustic method is an absolute flow measurement method that does not require calibration by comparision to another flow measurement method.

System Accuracy / Measurement Uncertainty

For pipeline flow measurement using a 4-path flowmeter, the accuracy of the rate indication and totalization of flow is specified to be plus or minus 0.5 percent of actual flow for all flows with velocity above 1 foot per second and up to maximum flow, provided the flowmeter is installed according to Accusonic specifications in a section of pipe with a minimum of ten diameters of upstream straight pipe. For installations having between four and ten diameters of straight pipe upstream of the meter section, four crossed paths (eight paths total) are required to maintain an accuracy of plus or minus 0.5 percent of flowrate.

To assure the specified accuracy, the flowmeter integrates the four velocities for each measurement plane (one for four path, two for four crossed paths) to calculate flowrate. Where crossed paths are used, the flowmeter software is designed to utilize velocity information from each plane of transducers to quantify and correct for crossflow.

System accuracy is determined by assigning an expected error to each componenet of flow measurement and then defining the total system uncertainty (accuracy) as the square root of the sum of the squared values of the individual errors. Sources of error for pipeline flow measurement are:

- Path Length Measurement
- Path Angle Measurement
- Travel Time Measurement
- Radius Measurement
  (or area for non-circular conduits)
- Velocity Profile Integration Error

Numerically, the analysis is as follows:

1. Path length measurement is typically done with the pipe dewatered. Using steel tape measures in larger pipes and calipers or micrometers in smaller pipes, individual path length uncertaintl is less than 0.15% (e.g., a 1/16-in (1.5mm) error in a 4-ft (1.2m) path length would result in a 0.13% error in velocity calculation). However, since there are 4 paths and the error is random, overall flow measurement uncerainty due to path length measurement error would be:

$$E_L = \tfrac{1}{4} (4 \times 0.0015)^{1/2} = 0.00075 \text{ or } 0.075\%$$

2. Path angle measurement is typically done with the pipe dewatered using a theodolite. The theodolite is capable of measuring angles to within ±20"; however, the primary source of error is the ablility to set the theodolite up on the pipe centerline. Careful set-up, according to Accusonic procedures, will assure that the theodolite is within ±0.1° (±6') of the true centerline.

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So for paths nominally at 45°, the flow measurement uncertainty due to path angle measurement error would be:

$E_{\varnothing}$ = (1-(cos 45.10/cos 45.00)) = 0.0017 or .017%

The above analysis assumes that there is no cross flow in the pipe (due to upstream disturbances such as elbows). This assumption is good for applications wehre there are at least 10 diametes of upstream straight pipe. For less available straight pipe, cross paths may maintain accuracy see Operating Principle).

For cross path installations, the above error is reduced to the theodolite resolution.

3. Travel Time Measurement is dependent on the digital oscillator accuracy, oscillator frequency, the ability of the received circuitry to consistently recognized the same point (leading edge on each received pulse, and the accurate subtraction of transducer, cable and system time delays. A precision oscillator (typically 160 MHz), accurate to within ±0.01%, is used for timing. Delay times are calculated and verified in the laboratory. The patented Accusonic Signal Quality Monitory (SQM) system ensures that the first negative edge of the received pulse will be considered to be the received point, for timing purposes. The flow measurement uncertainty from all timing errors is to calculated to be:

   E_T = 0.001 or .01%

4. Radius measurement is typically done from the inside with the pipe dewatered. The radius is measured at several sections to account for normal pipe out-of-roundness and give an average radius through the meter section. When done according to Accusonic procedures, the radius measurement can be completed to within ±0.02% (e.g., for a 6-foot (1.8m)-diameter pipe, the radius is measured to within1/16 in (1.5mm) or for a 10-foot (3m)-diameter pipe, the radius is measured to within 1/8 inch (3mm)).

   The flow measurement uncertainty due to radius measurement error is:

   $E_R = (1 - (1/1.002)^2)$ = 0.004 or 0.4%

5. Velocity profile uncertainty is estimated by numerical analysis of the ability of a 4-path integration to fit simulated velocity profiles. The uncertainty due to profile integration error is determined to be less than:

   $E_I = (E_L^2 + E_q^2 + E_T^2 + E_R^2 + E_L^2)^{1/2}$

   = 0.0049 @ 0.005 or 0.5%

   For other situations such as open channel systems, 2-path systems, compound meters, etc., the accuracy would be determined through an error analysis similar to the above, with the additional sources of error considered. For example, for an open channel system, there would be additional uncertainties due to level measurement and surface velocity deterination.

   Typical system uncertainties for various meter applications are presented in Table 1.

Table 1
Uncertainty Values for Various Flowmeter Configurations

Description	Typical Uncertainty
4- or 8- path pipeline system	±0.5% of actual flowrate
2-path pipeline system	±1.5% of actual flowrate
4-path open channel system	±2.0% of actual flowrate
2-path open channel system	±5.0% of actual flowrate

The accuracy of Accusonic multipath flwometers has been well proven in numerous independent laboratory and field tests conducted by the EPRI and others on a variety of large-diameter pipes..