Accusonic Flowmeter Systems
for
Sewer Flow Monitoring

Overview - Model 7510 Flowmeter

The Accusonic Model 7510 Flowmeter is designed for accurate, reliable flow measurement in pressurized pipes, open channels, and gravity-flow pipes flowing partially full through surcharged. The Model 7510 provides multiple pipe/channel flow monitoring and can accommodate a total of 8 acoustic paths that may distributed among up to four (4) separate metering sections. The high flowrate measurement accuracy, flexible configurations, and reliable performance under challenging flow monitoring conditions has resulted in widespread use for the Model 7510 Flowmeter for wastewater and sewerage collection system applications.

When used for open-channel applications or in pipes/conduits flowing partially full, such as sewer pipes, the Model 7510 Flowmeter measures average flow velocity across the flow profile at the elevation of each acoustic path, and water level (stage) is also measured and tracked as part of the flowrate calculation. The measured data acquired from the acoustic paths that are submerged are used for flowrate determination, along with the stage measurement and the geometry of the pipe or channel to determine cross-section area of the flow.

The multiple-path configurations provided with Accusonic flowmeter systems provide much greater accuracy in sewer flow monitoring applications than can be achieved via flowmeters limited to a single acoustic transit-time path across the flow cross-section velocity profile. In addition, crossed-path configurations available with Accusonic flowmeter installations provide compensation to maintain flowrate measurement accuracy in the presence of off-axis (cross-flow) velocity components that may be present at metering locations downstream from bends or other sources of disturbances to axial flow. Such cross-flow compensation at each acoustic path elevation is not available with any other flow measurement technology presently available for sewer flow monitoring.

The issues of flow velocity-profile estimation and effects of cross-flow on flowrate measurement accuracy are further discussed below.

Single-Path vs. Multiple-Path Flow Measurement

The Model 7510 Flowmeter utilizes the internationally accepted multiple-path ultrasonic (acoustic) transit-time method to determine flowrate in open channels in compliance with International Standard ISO 6416 (ref. 1). Water level measurements, together with accurately measured as-built dimensions of the installation, are required to calculate the flow area, and to determine the ratio of the path elevations to that of the water surface.

From these, the average water velocity in the channel is estimated. When only one path is operational, this is based on an assumed vertically velocity profile (ISO 6416 clause 2.8.6 & Table 4, presented below).

With the Model 7510 flowmeter when only one path is submerged, flowrate is computed from the measured variables Water Level and the Single-Path Velocity, and the fixed parameters describing the flow conduit cross-section.

Flowrate Determination with Single Acoustic Path Submerged

Q = (Flow Units Scale)*(Cross-Section Flow Area)*(Single-Path Velocity)*(Path Position Coeff.)

where: Cross-Section Flow Area = the cross-section area of flow at the measured water level (depth), computed using layer data.

The Model 7510 flowmeter path position coefficient is obtained by interpolation from the following look-up table (from ISO 6416, Table 4). Note that this is closely related to the theoretical open-channel vertical velocity distribution used by the U.S. Geological Survey (USGS), as noted in ASTM D 5389-93: *Standard Test Method for Open Channel Flow Measurement by Acoustic Velocity Meter Systems* (Ref. 2).

Ratio of path depth below surface to depth of water	Ratio of mean velocity to single-path velocity in the vertical.
0.1	0.846
0.2	0.863
0.3	0.882
0.4	0.908
0.5	0.937
0.6	0.979
0.7	1.039
0.8	1.154
0.9	1.424
0.95	1.650 (extrapolation)

Note that if a single-path velocity estimation procedure is used that does not utilize a procedure similar to the above for relating the measured path velocity to the mean flow velocity as a function of the path elevation in relation to the total water depth (i.e., taking account of varying water depth conditions), flowrate estimation error can approach ± 15%. If it is possible to calibrate the system by carrying out a check gauging, then this uncertainty can be reduced to ± 10% using the methods described in ISO 6416.

Using a multiple-path flowmeter, the velocity profile can be estimated during the higher flow periods when more than one path is operational, and this information can then be used to assess the relation between the mean velocity and the readings from the single submerged path under lower flow conditions.

The problems in achieving good flowrate measurement accuracy are even greater when acoustic path elevation placement for a single-path flowmeter installation is constrained to be a sizeable fraction of the full-pipe diameter.

Minimum Elevation of Acoustic Paths and Signal Detection Method

Note that the "minimum distance above the bottom" constraint also applies as a "minimum submergence below the water surface" criterion. The basis of the constraint arises from reflected ultrasonic signals from the water surface or bottom that can interfere with the direct-transmitted signals along the true acoustic path (this is termed "multi-path interference" in radio transmission/reception).

Accusonic flowmeters utilize a 1st-negative, leading-edge signal detection process that is least sensitive to this type of reflected interference, and the "minimum height above the bottom or minimum depth below the water surface" (H_{min}) for an acoustic path is prescribed as:

H_{min} = Square Root { (L * C) / 2F } = minimum height above bottom for lowest acoustic path

where L = acoustic path length,
C = sound velocity,
F = acoustic frequency.

H_{min} is dependent upon the path length L (pipe diameter) but is typically on the order of ~ 2-in or less for sewer applications. Thus, flow depths > than 4-in. can be monitored via the lowest acoustic path placed at 2-in. elevation.

Flowrate Determination with More Than One Path Submerged

With the Accusonic Model 7510 Flowmeter, when paths at more than one elevation are operational, flowrate is determined via the "mean-section" method, (ISO 6416 clause 2.8.4.4).

In addition, the Accusonic Model 7510 flowmeter estimates the water velocity at the surface by a weighted extrapolation of the velocities from the uppermost two paths below the surface, and uses this to more accurately model the vertical velocity profile.

The uncertainty of the open-channel flowrate measurement when paths at 2 elevations are operational is approximately ± 5% to 7%, based on ISO 748 (1997) Table E4.

With 3 paths operational, the open-channel flowrate uncertainty falls to ± 2% to 3%.

In addition to enhanced flowrate measurement accuracy due to the above-noted considerations, multiple-path transit-time flowmeters offer an inherent built-in redundancy that allows the flowmeter to continue operating in a reasonably accurate fashion even if one or two acoustic paths become inoperative due to severe fouling or covering by debris.

Cross-Flow Effects on Flowrate Measurement Accuracy

In addition to the increased flowrate measurement uncertainties (errors) associated with estimation of the actual mean flow velocity based upon single-path or point-velocity measurements taken within a limited region of the flow cross section, susceptibility of flowmetering systems to cross-flow error due to off-axis flow velocity components may also be a significant consideration.

This is discussed in ASTM D-5389 (Sec. 13.1.3, Ref. 2) which notes:

"This may be the largest potential source of errors for a single-path velocity measurement...each 1° error in assumed (axial) direction of flow...will result in a 1.76% error in velocity measurement. This error increases as the path angle increases. If two crossed 45° paths are used and the outputs averaged, for practical purposes, this error is zero".

Note that Accusonic flowmeters typically utilize a 45° acoustic path (crossing) angle, as called for in the ASTM standard noted above, and Accusonic flowmeter systems always provide the option of utilizing crossed-path configurations, at multiple elevations across the flow, to effectively mitigate cross-flow induced errors such as noted above.

Utilizing crossed-path configurations is not possible with single-path transit-time flowmeters.

In addition, flowmeters utilizing steeper acoustic path angles (> 45°) relative to the flow axis are inherently more sensitive to cross-flow error as noted above. Thus, a 65° acoustic path angle results in 2x the cross-flow error noted above for a 45°-path angle.

Note also that cross-flow error (the basis for which arises from making an assumption that the true velocity vectors are precisely aligned with the pipe axis) is also a concern with the use of multi-beam range-gated Doppler flowmeters, where steep beam-to-pipe-axis angles are quite sensitive to cross-flow effects and can introduce significant bias error into the flow measurements where small cross-flow components may be present.

An Important Note re Aerated Flow Limitation

Please note that proper operation of any ultrasonic transit-time flow measurement system requires that the flow stream in the measurement location is free of visible or microscopic entrained air bubbles that interfere with effective transmission of the acoustic signals. Locations that are downstream from waterfalls, weir overfalls, undershot sluice gates, large hydraulic jumps, or cavitating pumps are generally not good choices for installation of a transit-time flowmeter due to aerated flow conditions. No ultrasonic transit-time flowmeter will operate under aerated flow conditions.

Hydraulic Flow Conditions and Flowrate Measurement Accuracy

Factors affecting flowrate measurement accuracy for the Accusonic Model 7510 Flowmeter are discussed in detail in the document entitled: *Traceability and Uncertainty in Flowrate Determinations for the Accusonic Model 7510 Multiple-Path Ultrasonic Transit-Time Flowmeter*.

Accusonic multiple-path transit-time flowmeters using 4-path or 8-path (4-paths x 4-paths) configurations can be installed in pipes > 30-in.-diam. Accusonic flowmeters have been successfully installed and used for long-term sewer/CSO flow monitoring in very large applications including a 24-ft-wide (7.3-m-W) x 17.5-ft-high (5.3-m-H) arched sewer interceptor for the Greater Detroit Regional Sewer System (a project summary sheet including a photo of this sewer installation is in the Accusonic product literature folder).

Accusonic flowmeters may be used under a very wide range of hydraulic conditions, including backwatered flow, bi-directional flow, clean water conditions, turbid flow conditions (raw sewerage), very shallow flows (~ 4-in. flow depths), and very large pipes & channels.

Accusonic flowmeters may be utilized under low flow velocity conditions as well as high velocity conditions. Measurement accuracy may begin to decrease under low-velocity conditions. This generally depends on the pipe diameter (path length), but specified accuracies are generally achieved for a 36-in.-diam. (1-m-diam.) pipe with velocities > 0.5 ft/sec (0.15 m/sec). Specified accuracies are maintained in larger pipe diameters under lower velocity conditions.

Flowrate measurement accuracy can always be improved via use of longer-period flowrate averaging, e.g., use of 5-min. to 15-minute averaging, as contrasted to a 15-sec to 60-sec average (this may be programmed selectively into the flowmeter for each site). This must be carefully considered for each site in light of project requirements and objectives.

Accusonic flowmeters are designed to be used under wide-ranging hydraulic flow conditions, ranging from shallow dry-weather flow conditions through surcharged wet-weather flows. The use of acoustic paths positioned at multiple elevations across the pipe or channel provides an ideal means to accommodate flowrate measurement under wide ranging water levels. Flowrate measurement accuracy improves under full-pipe (surcharged) flow conditions, since water level measurement is no longer a factor in the overall measurement uncertainty.

Reversed (bi-directional) flow is measured with essentially the same accuracy/resolution as normal flow. This assumes similarity in the upstream/downstream approaches to the measurement section.

At typical manhole-access sewer flow monitoring sites, the flow measurement section is installed in the influent pipe (normally upstream) to the manhole chamber. Under backwatering, reversed flow conditions, the manhole chamber located in close proximity to the measurement section can represent a significant hydraulic flow disturbance, resulting in cross-flow (off-axis) velocities in the measurement section. This would usually result in reduced measurement accuracy using most flowmeter technologies. However, Accusonic flowmeters can be configured using symmetrically crossed acoustic paths in order to mitigate these effects and thus minimize any measurement errors associated with such cross flow. (see discussion re cross-flow error above)

Water Level Sensors (Pressure Sensors and Ultrasonic Down-Lookers)

Water level sensor readings (for open-channel and partially full pipe flowmeters) should be checked periodically to ensure that the sensors are reading the correct depth of flow. When redundant water level sensors are in place, comparison of the readings may be used to detect drift of the water level sensors. Verification of the actual depth of flow typically requires entering a pipe for making a physical measurement of flow depth, against which the water level sensors should be checked and adjusted, if necessary.

Periodically the pressure and ultrasonic down-looking water level sensors must be serviced for proper operation. This includes cleaning of the transducers, re-calibration of the pressure transducers if necessary, and changing dessicant for the pressure vent tube. Adjustment of flowmeter parameters for any sediment build up in the measurement section may be required, if such build-ups are significant and cannot be routinely cleared from the site.

There is no surcharge limit associated with the use of Accusonic flowmeters, although pressure sensor range for each site must be selected according to highest expected surcharge level. This is because pressure sensors typically are specified to be capable of a 2x - 3x over-pressure in excess of its specified measurement range before experiencing loss of calibration or damage to the sensor.

Remote Flowmeter and Data Access

The Model 7510 Flowmeter, when configured with telephone modem and internal datalogging capability, provides an excellent means for remote flowmeter status checking, fault diagnosis, and troubleshooting using *AccuFlow®* Windows®-based PC user-interface software.

The Model 7510 Flowmeter offers flexible interfacing capabilities for network telemetry and SCADA systems. These include 4-20 mA isolated analog output channels and contact-closure relay outputs that may be interfaced to remote terminal units (RTUs) used for network communications via fiber optic, cable, telephone line or radio (RF) telemetry links.

In addition, the Model 7510 offers a variety of bi-directional serial digital communications capabilities for direct and remote communications within a network host computer system, including modem-based RS-232 communications links used in conjunction with the flowmeter's internal datalogger and the *AccuFlow®* software interface. MODBUS and ethernet interfaces are available as optional outboard components for the flowmeter system. Modem-based communications may be implemented via commercial dial-up telephone line or via dedicated telephone, fiber optic, or RF communications.

Intrinsically Safe Flowmeter Installation in Potentially Explosive Atmospheres

Accusonic offers several laboratory-certified transducers for "intrinsically safe" installation in sewers and other potentially explosive atmosphere environments (NEC Class I, Division 1, Groups C,D locations).

Intrinsically safe systems limit the amount of electrical energy that is available so that an ignition cannot occur in the presence of an explosive gas. Typically, this reduces the amount of power/energy that can be applied to the acoustic transducers, and the limited energy results in much shorter acoustic transmission distance so that use in large pipes/channels may be a problem.

Accusonic has developed a proprietary, patented (US Patent No. :6, 044, 714) high-signal-strength flowmeter transmitter that has been laboratory-certified for use with intrinsically safe transducers that achieves full ultrasonic signal strength in these difficult sewer flow environments, while meeting the required intrinsically safe criteria for use in potentially explosive atmospheres. This technique provides vastly superior flow measurement performance and reliability of operation and has been proven in hundreds of sewer flowmeter installations.

Intrinsically safe certification and operation is critical for successful and safe flowmeter installation and use in sewer and wastewater flowmeter applications.

Intrinsically safe certification and operation is critical for successful and safe flowmeter installation and use in sewer and wastewater flowmeter applications.

Note that intinsically safe installations offer significant cost and safety advantages versus "explosion-proof" type installations. Explosion-proof configurations utilize gas-tight enclosures, cable conduits, and seals to ensure that no explosive gas is allowed to come into contact with any component (including cabling) of the flowmeter system - all of which results in significantly higher cost and greatly complicated flowmeter system installation and use.

Flowmeter Maintenance and Remote Diagnostics

The flowmeter uses automatic gain to detect and process each acoustic signal. These gain values can be logged and trended over time to evaluate performance of transducers and cables and determine when maintenance may be required. Other variables reported on the system indicate signal-to-noise ratios and system integrity. Finally the "Oscilloscope Mode" can be used to observe acoustic signal waveforms to verify proper shape and detection for each acoustic path.

Very little routine maintenance is required for Accusonic transit-time flowmeters. The meters are "dry" calibrated during installation, based upon precise determination of pipe dimensions and acoustic path geometry, and do not generally require re-calibration over time. A periodic inspection of the flowmeter operating parameters versus those installed at the time of system commissioning is recommended to ensure that a parameter has not been inadvertently changed.

Much information can be gained from on-site or remote (modem-based) communication with the flowmeter console, utilizing the *AccuFlow®* software, which provides status information on the meter section and on the performance of individual acoustic paths.

An important diagnostic tool resides in the Automatic Gain Control (AGC) feature, which automatically adjusts the gain (amplification factor) of the acoustic receiver according to the signal strength of the received acoustic pulse and the relative level of "background" noise. The gain for each acoustic path is controlled independently. Monitoring the gain levels for increasing trends over time will alert the user to possible need for cleaning of the transducers or checking integrity of cabling and connectors. If gain levels stay stable over time, no maintenance is required.

AccuFlow® **Windows®-Based PC User-Interface Software**

AccuFlow® is system-resident software and may be loaded onto PC-type computers, providing Windows®-based communications with the flowmeter system. This Windows® Interface software allows project-authorized personnel to easily configure the flowmeter for specific operational conditions; provide capability for flow data retrieval, archiving, and display; and provide an “oscilloscope function” for evaluation of acoustic transit-time signal wave form characteristics.

AccuFlow® includes four modes for operator use, comprising:

1. Setup Wizard
2. Site Commissioning
3. Real-Time Data Collection and Storage
4. On-Line Flowmeter Diagnostics and Oscilloscope Function

Flow data is stored on the internal flowmeter 2-Mbyte datalogging board in flash RAM memory and can only be accessed via the *AccuFlow®* software. Once the data is retrieved into a user PC (either via direct-connect to the flowmeter console or via modem-based remote access), it is stored in the master data_log directory in a sub-directory within *AccuFlow®* file structure via a user-provided file name. Flowrates, water levels and flow velocities are stored in flowmeter section sub-directories, and may be viewed using the “Review Historical Data" function from the main menu.

Section totalized volume and water temperature are also stored in the section sub-directories. The sum of flowrates and sum of totalized volumes for a multiple pipe/section meter are stored in the “S” file, individual acoustic path data are stored in “P” files, and water level data is stored in the “L” file. The file names therein contain the date and the above noted letter codes. For example, if the data log period began on May 25, 1997, the data for path 1 (VSound, gains, times) will be stored in a file named “05297PO”. Files are ASCII comma-delimited text for import into standard spreadsheets.

The sub-directory tree structure that is created to store the data downloaded from the datalogging board is shown below. The number and types of files may differ slightly from site to site depending on the particular system configuration in use. The top of the tree (Data_Log) is found in the sub-directory where the *AccuFlow®* software has been installed. The first branch below Data_Log (labeled D in the tree structure) will be the sub-directory name entered by the user during the data download process.

The file naming convention used is based on the start date of the specific data that is downloaded. For example, if the datalogging operation began on April 1, 1999, the mmddyy portion of the names shown will be replaced with “040199”. The last one or two characters in each filename (shown in bold) indicate the type of data stored in each file, described below.

- **Qn** indicates flowrate and level data for section n where n indicates the section no. 1 through 4.

- **Vn** indicates the velocity data for section n. The velocity data file will store the velocity data for all paths in the system (i.e., for all flow measurement sections). For example a 4-section system (i.e., 4 separate pipe or channel measurement sections) with 2 paths in each section (combined total of 8 paths) will store the velocity data redundantly for all 8 paths in each section subdirectory.

- **Tn** indicates the volume and temperature data for section n.

- **S** indicates the system flowrate and volume that is simply the combined sum for all sections.

- **L** indicates the water level measurement data for each of the active level measurement inputs. This data consists of two parts, the first part contains the level data for each of the active level inputs scaled in engineering units (feet, meters, …). The second part contains the raw binary value as read from the A/D converter for each of the active level inputs.

- **E** contains the path error, section error and level error status values. These values are the decimal equivalents of system binary values.

- **Pn** contains the path data for path n. This data comprises:
  - the velocity of sound determined by the velocity measurement travel times
  - the gain required to obtain a useable signal level
  - the percentage of the full scale A/D resolution that the received signal achieved
  - the measured signal-to-noise ratio
  - average of forward and reverse travel times when the operating in envelope-detect mode
  - average of forward and reverse travel times when operating in the zero-crossing detect mode
  - difference between forward and reverse travel times, calculated as Trev – Tfwd

For a 15-minute logging interval, one month of data will use approximately 1.2 MBytes. The memory capacity of the datalogging system enables 27 parameters (logged at 15-minute intervals) to be stored in the flowmeter for 11 weeks without overwriting the data.

Logged Data Directory Structure

- Data Log
  - User Name Entered
    - Sect 1
      - mmddyyQ1 - Date,Flow1,Level1
      - mmddyyV1 - date,velocity 1 - 10
      - mmddyyT1 - date,volume1,temperature1
    - Sect 2
      - mmddyyQ2 - Date,Flow2,Level2
      - mmddyyV2 - date,velocity 1 - 10
      - mmddyyT2 - date,volume2,temperature2
    - Sect 3
      - mmddyyQ3 - Date,Flow3,Level3
      - mmddyyV3 - date,velocity 1 - 10
      - mmddyyT3 - date,volume3,temperature3
    - Sect 4
      - mmddyyQ4 - Date,Flow4,Level4
      - mmddyyV4 - date,velocity 1 - 10
      - mmddyyT4 - date, volume4,temperature4
    - mmddyyS - date, flowSum,volumeSum
    - mmddyyL - date, level1 - 4, bits1 - 4
    - mmddyyE - date, PathError,SectionError,LevelError
    - mmddyyP0 - date, Vsound1,dB1,Gain%1,S/N1,Tenv1,Travel1,Delta1
    - mmddyyP1 - date, Vsound2,dB2,Gain%2,S/N2,Tenv2,Travel2,Delta2
    - mmddyyP2 - date, Vsound3,dB3,Gain%3,S/N3,Tenv3,Travel3,Delta3
    - mmddyyP3 - date, Vsound4,dB4,Gain%4,S/N4,Tenv4,Travel4,Delta4
    - mmddyyP4 - date, Vsound5,dB5,Gain%5,S/N5,Tenv5,Travel5,Delta5
    - mmddyyP5 - date, Vsound6,dB6,Gain%6,S/N6,Tenv6,Travel6,Delta6
    - mmddyyP6 - date, Vsound7,dB7,Gain%7,S/N7,Tenv7,Travel7,Delta7
    - mmddyyP7 - date, Vsound8,dB8,Gain%8,S/N8,Tenv8,Travel8,Delta8
    - mmddyyP8 - date, Vsound9,dB9,Gain%9,S/N9,Tenv9,Travel9,Delta9
    - mmddyyP9 - date, Vsound10,dB10,Gain%10,S/N10,Tenv10,Travel10,Delta10

A diskette containing a demonstration version of the *AccuFlow*® PC user-interface software is available for customer familiarization. The demo software includes data files from actual flow monitoring sites to provide hands-on experience with this Windows®-based software interface. An additional diskette is available containing data for a 30-day period from a tidally influenced CSO site with reversing bi-directional flow measurement.

List of Accusonic Sewer Flowmeter Network Projects

- Allegheny County Sanitation (ALCOSAN)
- Greater Detroit Regional Sewer System
- Quebec City Real-Time Sewer/CSO Network
- Somerset Raritan Valley Sewerage Authority (Bridgewater, NJ)
- Wayne County Down River Project

Reference/Contacts re Accusonic Sewer Flowmeter Projects

BPR-Asseau Engineers Quebec City, Quebec	Denis Simard (418) 871-3414 ext. 5066
Camp, Dresser & McKee Detroit, MI	Mark Tenbroek (313) 963-1313
Camp, Dresser & McKee Pittsburgh, PA	Terry Meeneghan (412) 201-5500
Hubble, Roth & Clark Bloomfield Hills, MI	Kim Chapman (248) 338-9241
Martin Control Services Plymouth, MI	John MacDonald (734) 453-4301
Mass. Water Resources Authority Boston, MA	Phil Carbone (617) 305-5856
Somerset Raritan Valley Sewer Auth. Bridgewater, NJ	Tony Gencarelli (732) 469-0593

Referenced Documents

1. ISO 6416 (1992): *Measurement of liquid flow in open channels - Measurement of discharge by the ultrasonic (acoustic) method.* Doc. Ref. No. ISO 6416 1992(E).
   International Organization for Standardization, CP 56, CH-1211 Geneva 20, Switzerland.

2. American Society for Testing and Materials (1993): *Standard Test Method for Open Channel Flow Measurement by Acoustic Velocity Meter Systems,* Doc. No. D 5389-93.
   Annual Book of ASTM Standards, ASTM, Philadelphia, PA.

3. Accusonic (1999): *Traceability and Uncertainty in Flowrate Determinations for the Accusonic Model 7510 Multiple-Path Ultrasonic Transit-Time Flowmeter*.
   Accusonic Technologies, 25 Bernard Saint Jean Dr., E. Falmouth, MA 02536.