FSI Acoustic Current Meter Provides Basis for Complete Hydrographic Monitoring Station

Abstract

Falmouth Scientific, Inc. 2 Dimensional Acoustic Current Meter (2D ACM) offers an integrated platform in which to measure current, temperature, depth (tide), sound-velocity and salinity data. Using the phase-shift acoustic transit-time measurement technique, the 2D ACM is an easy-to-use, high accuracy current meter, with no moving parts and a finite measurement volume. The phase-shift measurement principle allows the 2D ACM to measure accurately, even in slow moving water and in water with no reflectors present (e.g. deep water). Internal compass and tilt sensors provide magnetic horizontal current vector direction, without the need for specific orientation of the current meter during deployment.

Optional integrated Conductivity, Temperature, and Depth (CTD) sensors provide temperature, salinity and depth information. With the CTD fully integrated into the current meter hydrographic users are provided with a single measurement platform and data logger capable of collecting a broad spectrum of data, in addition to simple current information.

System Configuration

The FSI 2D ACM/CTD is an integrated package with a central battery-powered central processing unit/data logger, acoustic current meter, and conductivity, temperature and depth (CTD) sensor module.

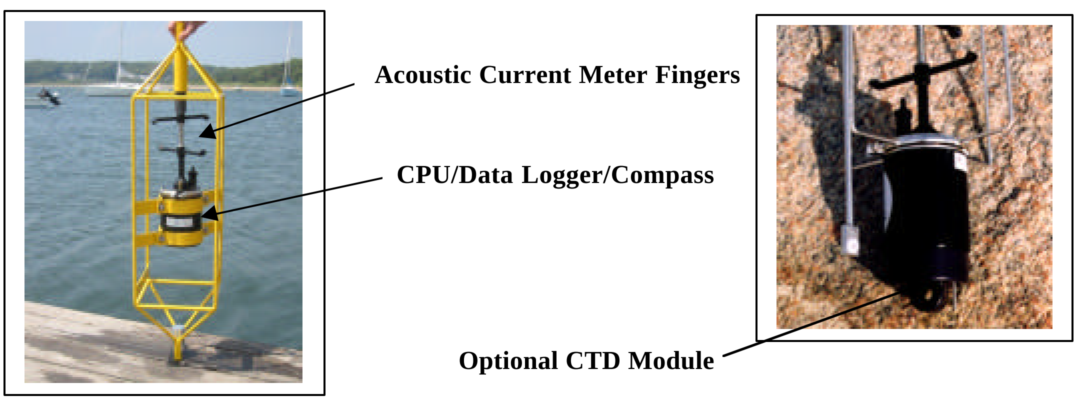

Figure 1 – FSI 2D ACM in Mooring Frame

The acoustic current meter module consists of a set of sensors mounted on *fingers* mounted above the electronics module. The acoustic sensors or transducers are mounted in opposing pairs in an orthogonal configuration. As described below, there are four pairs of transducers to allow full resolution of the current velocity vector magnitude and direction in a 3-dimensional field. To prevent damage to the electronics if the acoustic fingers are damaged or broken, the acoustic fingers are isolated from the electronics module, using a seal-pin type feedthrough connector.

The central pressure housing contains the battery pack, CPU, data logger, compass/tilt sensor, ACM processor and communications module. All electronics utilize ultra-low power consumption components mounted on easily replaceable circuit cards, allowing extra-long battery life and simplified field service. The pressure module utilizes redundant compression and piston pressure seals to prevent the possibility of water intrusion and damage.

The CTD module resides below the central pressure housing and incorporates separate conductivity, temperature and pressure sensors. The conductivity sensor utilizes FSI's patented inductive measurement technique. The sensor is molded in a phenolic resin and is extremely rugged and resistant to biofouling effects. Accuracy of the conductivity measurement is +/- 0.03 mS/cm. The temperature sensor is a high-accuracy platinum resistance-type thermometer (PRT), capable of temperature measurement to within +/- 0.03 °C. The pressure sensor is a Druck® precision-machined silicon sensor, with FSI-calibrated temperature compensation, that measures depth to +/- 0.01 % of full scale. This allows the unit to be used for accurate tidal variation measurement. The instrument incorporates UNESCO and PSS equations to calculate salinity and sound velocity from the CTD information, to provide extremely useful information to the end-user.

System Set-up and User Interface

User interface with the FSI 2D ACM is via an easy-to-use Windows®-based program. Meter configuration and deployment parameters are entered via standard pull-down menus. User set-up options include:

- Operating mode (continuous or interval)
- Operating cycle (interval and on-time)
- Parameters to be logged
- Calculation options
- Communications options
- Data storage and retrieval options

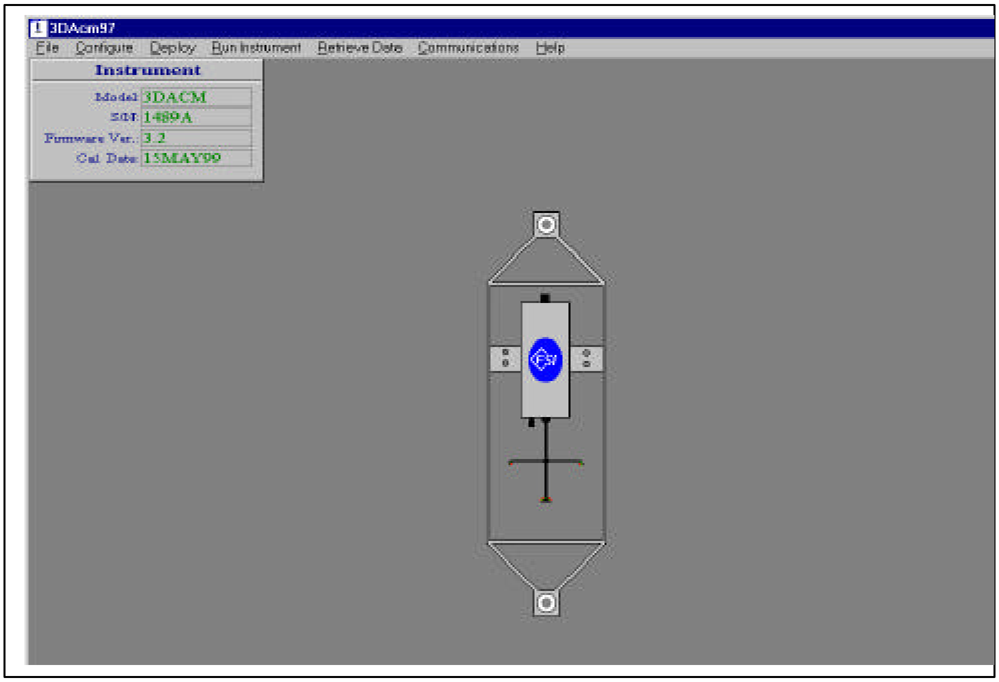

Figure 2 – Graphic User Interface

Using the menus available, set up is simple and intuitive, but offers extensive capability.

Data Collection and Output

The 2D ACM collects data either continuously or at user-selected intervals. This flexible operating capability allows the 2D ACM to be used for a variety of applications. With continuous data collection capability, the 2D ACM can be configured to provide real-time data collection and output, which may be useful in harbor or river applications where real-time current and tide information is useful for navigation. Continuous operation with direct readout may also be useful for on-station profiling activities where real-time review of data provides the user with instantaneous data quality review capability.

For long term deployments the 2D ACM can be set-up in an interval mode, with current- vector averaging, to allow periodic sampling over extended periods of time. In these applications, a 2D ACM is typically deployed on a mooring and operated using internal battery power. Data is logged internally and time/date stamped. Data download is done when the instrument is recovered using an RS-232 output and the FSI Windows®-based software. The low power consumption of the instrument, combined with interval operation and data compression allow deployments of more than one year, without the need to recover the instrument to download data or replace batteries.

Data output can be set-up as continuous, via RS-232 or RS-485 data link or on user demand by connection to the instrument.

Current Measurement Principle

The FSI Acoustic Current Meter measures current velocity by accurately measuring the differential travel-time of acoustic pulses propagated between multiple pairs of transducers, mounted at fixed, known locations in space. Each pair of transducers forms an acoustic *path*. Propagation of acoustic signals upstream and downstream on that path allows determination of the velocity vector component parallel to that particular path.

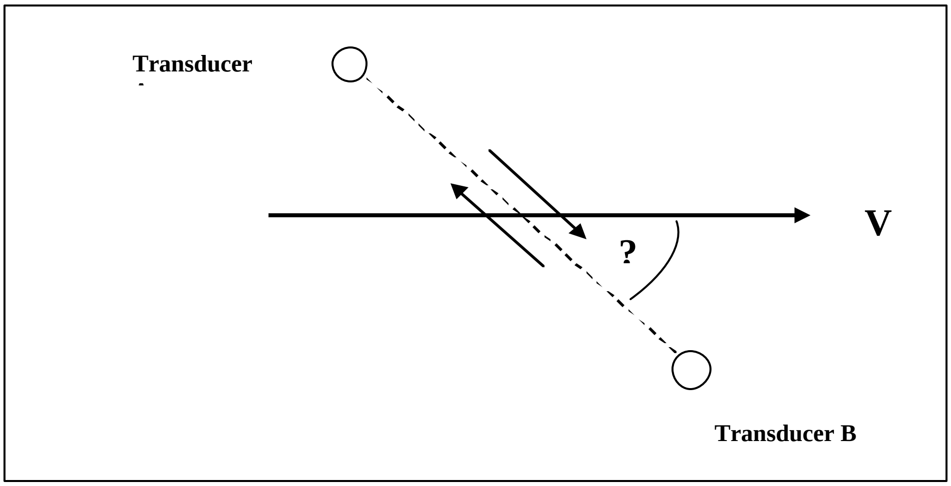

Figure 3 – Acoustic Path Arrangement

The velocity vector magnitude can be calculated according to the formula:

$$V =((T_{up}-T_{dn})/ T_{up}*T_{dn}))(L/2 \cos ?)$$

Where:

- **V** = current velocity vector magnitude
- **L** = path length between Transducer A and Transducer B
- **?** = Angle between acoustic path and current vector direction
- T_{up} = upstream travel time
- T_{dn} = downstream travel time

But since the speed of sound is very large with respect to the velocity the average travel time is essentially L/c, therefore:

$$T_{up}*T_{dn} \sim (L/c)^2$$

Where:

- **c** = speed of sound in water

So, the velocity equation may be simplified as:

$$V = ((T_{up}\text{-}T_{dn})\ c^2\ )/(2L\ \cos ?\ )$$

Since **L** is fixed and **c** is know by calculation[1], the only measured variable becomes (**Tup-Tdn)**, or the differential travel time. Since the speed of sound is very large compared to the current velocity, historically it was very difficult to measure this differential travel time accurately. The patented technique used in the FSI 2D ACM uses the ***phase-difference*** between upstream and downstream signals to determine this differential travel time. This is a highly accurate method of measuring very small differences between large numbers. For a 1 MHz signal, 1/2 cycle (180° of phase angle) = 0.5 microsecond. Since the FSI 2D ACM digitizes the 180° of phase angle using a 12-bit digitizer, the differential timing resolution of the instrument is 1.79×10^{-10} seconds, which corresponds to a velocity resolution of:

Resolution = 0.003 cm/sec

Since the angle of the velocity vector with the acoustic path is unknown, at least 3 acoustic paths mounted in an orthogonal configuration are required to determine velocity magnitude and direction.

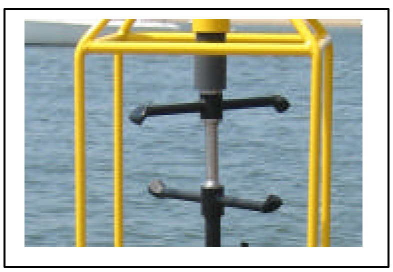

Figure 4 - Acoustic Path Arrangement

By determining the velocity component for each path, the true vector direction, relative to the current meter, may be determined by resolving the values as compared to the relative angles of each of 3 paths with respect to the meter. The 2D ACM actually uses 4 paths for measurement, then disregards the path downstream of the center stem of the current meter. This eliminates any error associated with disturbance of the current flow profile over the center strut of the meter.

[1] The speed of sound is calculated using an integral temperature sensor with the value calculated as a function of temperature in standard seawater. If the meter is to be deployed in fresh water, the user must change a user-selectable parameter to provide proper sound velocity correction.

Accuracy and Data Averaging

The FSI 2D ACM measurement technique provides extremely precise measurement of velocity vector magnitude and direction, relative to the instrument. As noted above the resolution is better than 0.01 cm/sec and the measurement cycle requires only about 300 msec to complete. This means that the current meter is capable of measuring minute variations in current vector magnitude or direction (e.g., turbulence). While measurement of these changes may be useful for some scientific experiments, most users prefer to look at averaged values to determine typical current vector information over a finite time period. Figure 5 illustrates data collected during a typical tow-tank test.

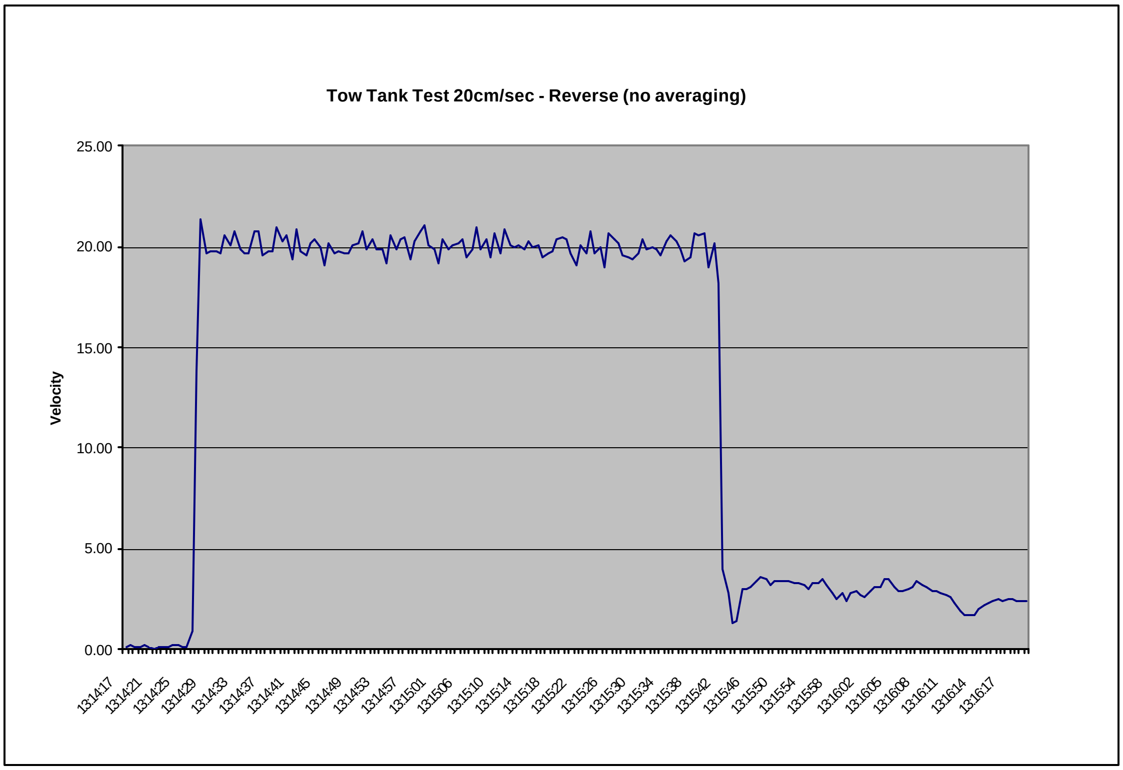

Figure 5 – Tow Tank Test of 2D ACM – Raw Data

The above data shows the results of towing a 2D ACM through a tank at a fixed 20 cm/sec velocity. Initial review of the data shows fairly accurate measurement, but with instantaneous results varying +/- 2 cm (~10%) from the true velocity value.

Since the 2D ACM is sampling at approximately 2Hz, it is actually measuring instantaneous changes in the current velocity vector. In a closed tank such changes should average quickly and show results close to the tow-velocity. Applying a 10-second box-car average to the above data yields the data shown in Figure 6. This uncorrected data demonstrates the 2D ACM's ability to measure the current velocity to within better than 0.1 cm/sec, even with a relatively low velocity of 20 cm/sec. This accuracy significantly exceeds that of mechanical propeller or rotor-type meters and even Doppler meters, at these velocities.

The data also demonstrates the need for the user to apply some averaging to the data. The graphical user interface allows the user to select averaging periods appropriate for each specific application. For example, while it may be appropriate to apply a 15- to 30-second averaging period to data collected when current profiling or sampling, it may be more appropriate to apply an averaging period of several minutes to moored, stationary current meters. This allows the user to collect current data uninfluenced by short-term variations (due to boat wakes, waves, local influences, etc.).

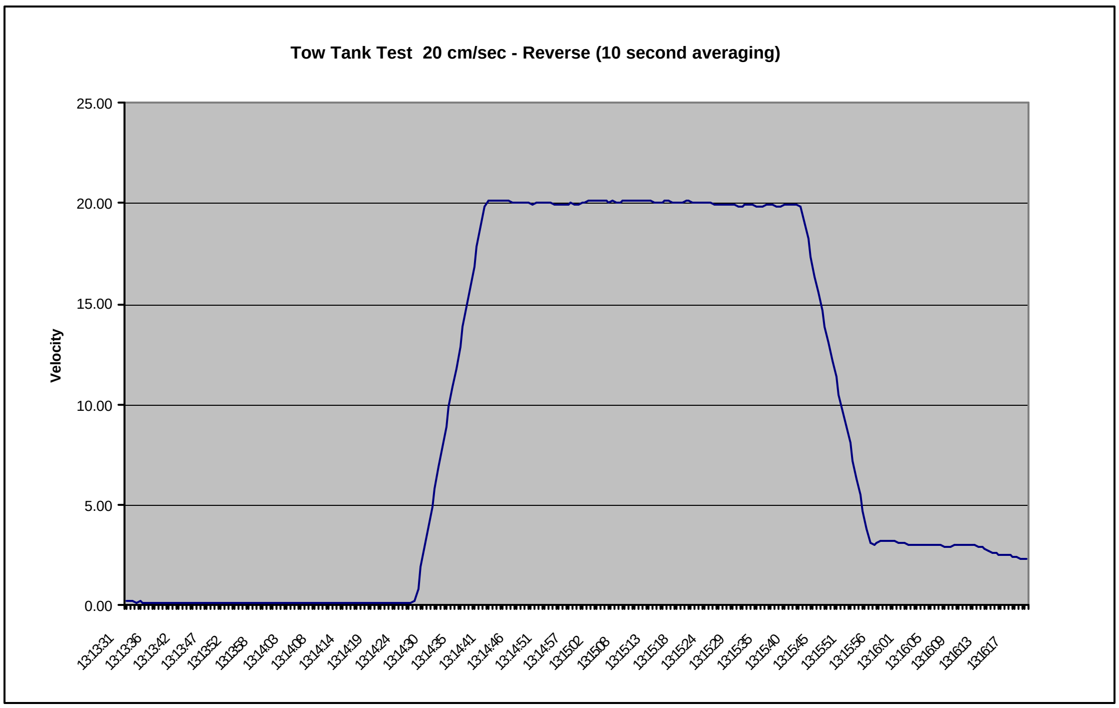

Figure 6 – Tow Tank Test of 2D ACM – Averaged Data

Internal Compass and Tilt Sensors

In the above discussion of current vector determination, it was stated that the acoustic paths are able to resolve the current velocity magnitude and direction relative to the current meter. For useful field current measurement, it is necessary to resolve current vector magnitude and direction to cartographic coordinates. While it may be possible to orient a current meter relative to North and Vertical with a very careful deployment, such a requirement would make deployments extremely difficult.

To allow the FSI 2D ACM to resolve current vector data to cartographic coordinates, the instrument incorporates internal compass, tilt and up/down sensors. Magnetic heading of the 2D ACM is determined using an FSI-developed compass system that utilizes a Honeywell® magneto-resistive chip to sense the magnetic orientation of the Earth's field. The instrument's variation from the vertical plane is determined using accelerometer-based tilt sensors. Finally the up/down orientation of the 2D ACM is determined using a gravity switch. Information from these sensors allows the 2D ACM to output current direction relative to the horizontal surface and magnetic north. If data relative to true north is required, data can be corrected in post-processing by applying local magnetic variation.

For applications where compass correction may cause measurement error the user has the option to output relative data, rather than compass corrected data. An example of where this might be required is a tow-tank test or when the instrument is used as a speed logger on a moving vehicle. If the instrument is moving, rather than stationary, its indicated heading will constantly change, creating an error in the reading. For any application where instruments are moving rapidly or accelerating, compass correction should be turned off to eliminate transient errors.

Another important consideration when deploying an instrument with internal compass correction is localized magnetic effects. Care should be taken to assure that there is no significant iron or magnetic source near the meter. Mooring cages should be carefully checked to assure they are non-magnetic. A simple hand-held compass can be used to check this.

Another very important magnetic source that is often overlooked is the internal battery. Batteries delivered from FSI are de-gaussed to eliminate their magnetic field. Any other battery should also be de-gaussed and carefully checked to assure there is no residual magnetism. If not properly handled, batteries can be a significant source of direction error.

Summary

The FSI 2D ACM offers today's hydrographers a powerful tool for collection of a variety of bathymetric data in a single platform. Vector-averaged current data may be collected along with temperature, salinity and tide variation. The instrument's compact design, lightweight housing and internal compass/tilt sensors make deployments simple and cost effective for long-term deployments. The 2D ACMs low power consumption and flexible configuration capability allow the system to be deployed for periods of more than one year. Significantly reducing maintenance and deployment/retrieval costs for most applications. The 2D ACM's graphical user interface makes the system easy for field technicians to handle instrument set-up, deployment and data retrieval.

The phase-shift operating principle is a direct-read current measurement method that does not rely on remote Doppler reflections of acoustic signals to determine current velocity. This means that the 2D ACM can measure accurately even in the absence of particles for signal reflection, in low velocity currents, and near water surface or bottom/mud layers, where Doppler meters become inaccurate due to spurious reflections or limited signal-to-noise.