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APPLICATION NOTE 27 **Revised February 2010**

Minimizing Strain Gauge Pressure Sensor Errors

The following Sea-Bird instruments use strain gauge pressure sensors manufactured by Paine Corporation:

- Some SBE 16 (not 16*plus*) SEACATs
- SBE 19 (not 19*plus*) SEACAT Profilers
- SBE 29 Strain-Gauge Pressure Sensors and SBE 25 SEALOGGER CTDs built prior to March 2001
- SBE 37 MicroCATs built prior to September 2000
- SBE 39 Temperature Recorders built prior to September 2000

Note: A small number of instruments that fall outside of the above categories also have Paine sensors; consult the instrument configuration information supplied with your instrument.

DEFINITION OF PRESSURE TERMS

The term *psia* means *pounds per square inch, absolute* (*absolute* means that the indicated pressure is referenced to a vacuum). The Paine sensors as supplied to Sea-Bird are designed to respond to pressure in nominal ranges 0 to 100, 0 - 300, 0 - 500 psia, etc.

For oceanographic purposes, pressure is most often expressed in *decibars* (1 dbar = 1.4503774 psi). A dbar is 0.1 bar; a bar is approximately equal to a standard atmosphere (1 atmosphere = 1.01325 bar). For historical reasons, pressure at the water surface (rather than absolute or total pressure) is treated as the reference pressure (0 dbar); this is the value required by the UNESCO formulas for computation of salinity, density, and other derived variables.

Some oceanographers express pressure in newtons/meter^2 or *Pascals* (the accepted SI unit). A Pascal is a very small unit (1 psi = 6894.757 Pascals), so the mega-Pascal (1 MPa = 10^6 Pascals) is frequently substituted (1 MPa = 100 dbar).

Since the pressure sensors used in Sea-Bird CTDs are *absolute* types, they inherently indicate atmospheric pressure (about 14.7 psi) when in air at sea level. Sea-Bird outputs pressure in one of the following ways:

- CTDS that output raw data (**SBE 16, 19, and 25**) and are supported by SEASOFT's Seasave (real-time data acquisition software) and SBE Data Processing (data processing software) – In SEASOFT, the user selects pressure output in psi (*not* psia) or dbar. SEASOFT subtracts 14.7 psi from the raw absolute reading and outputs the remainder as psi or converts the remainder to dbar.
- Instruments that can output converted data in engineering units (**SBE 37 and 39**) – The instrument subtracts 14.7 psi from the raw absolute reading and converts the remainder to dbar.

RELATIONSHIP BETWEEN PRESSURE AND DEPTH

Despite the common nomenclature (CTD = **C**onductivity - **T**emperature - **D**epth), all CTD instruments measure *pressure*, which is not quite the same thing as depth. The relationship between pressure and depth is a complex one involving water density and compressibility as well as the strength of the local gravity field, but it is convenient to think of a dbar as essentially equivalent to a meter, an approximation that is correct within 3% for almost all combinations of conductivity, temperature, depth, and gravitational constant.

SEASOFT offers two methods for estimating depth from pressure:

- For oceanic applications, salinity is presumed to be 35 PSU, temperature to be 0^o C, and the compressibility of the water (with its accompanying density variation) is taken into account. This is the method recommended in UNESCO Technical Paper No. 44 and is a logical approach in that by far the greatest part of the deep-ocean water column approximates these values of salinity and temperature. Since pressure is also proportional to gravity and the major variability in gravity depends on latitude, the latitude entry is used to estimate the magnitude of the local gravity field.
  - In Seasave V7: In Configure Inputs, enter the latitude on the Miscellaneous tab.
  - In SBE Data Processing's Data Conversion and Derive modules: Enter the latitude on the Miscellaneous tab.
  - For RS-232 version of SBE 37-SI that can calculate and output depth (firmware version ≥ 2.1): Enter the latitude for the depth calculation (if **OutputDepth=Y**) in the instrument's EEPROM using the **Latitude=** command in SEATERM (terminal program).
  - For RS-485 version of SBE 37-SI or 37-SM that can calculate and output depth (firmware version ≥ 2.2): Enter the latitude for the depth calculation (if **#iiOutputDepth=Y**) in the instrument's EEPROM using the **#iiLatitude=** command in SEATERM (terminal program).
  - For SBE 39 – User is prompted to enter latitude if conversion of pressure to depth is requested when converting an uploaded .asc file to a .cnv file in SEATERM.
- For fresh water applications, compressibility is not significant in the shallow depths encountered and is ignored in Seasave V7 and SBE Data Processing, as is the latitude-dependent gravity variation. Fresh water density is presumed to be 1 gm/cm and depth in meters is calculated as 1.019716 *pressure (in dbars). No latitude entry is required.

CHOOSING THE RIGHT SENSOR

Initial accuracy and resolution are expressed as a percentage of the full scale range for the pressure sensor. Paine sensors offer accuracies of 0.25% (100 - 1500 psia units) and 0.15% (3000 - 15,000 psia units). For best accuracy and resolution, select a pressure sensor full scale range to correspond to no more the greatest depths to be encountered. The effect of this choice on CTD accuracy and resolution is shown below:

Range		**Maximum Error (meters)**	**Resolution (meters)**
Pressure (psia)	**Depth (meters)**		
0 - 100	0 - 60	0.2	0.01
0 - 300	0 - 200	0.5	0.03
0 - 500	0 - 340	0.9	0.05
0 - 1,000	0 - 680	1.7	0.10
0 - 1,500	0 - 1,020	2.5	0.15
0 - 3,000	0 - 2,000	3.0	0.30
0 - 5,000	0 - 3,400	5.1	0.50
0 - 10,000	0 - 6,800	10.2	1.00
0 - 15,000	0 - 10,200	15.3	1.50

The meaning of *accuracy*, as it applies to these sensors, is that the indicated pressure will conform to true pressure to within ± *maximum error* (expressed as equivalent depth) throughout the sensor's operating range. Note that a 10,000-psia sensor reading + 10 meters at the water surface is operating within its specifications; the same sensor would be expected to indicate 6800 meters ±10 meters when at depth.

Resolution is the magnitude of indicated increments of depth. For example, a 10,000-psia sensor subjected to slowly increasing pressure will produce readings approximately following the sequence *0, 1.00, 2.00, 3.00* (meters). Resolution is limited by the design configuration of the instrument's A/D converter. For example, for the SBE 25 this restricts the possible number of discrete pressure values for a given sample to somewhat less than 8192 (13 bits); an approximation of the ratio 1:7000 is the source of the 0.015% resolution specification indicated for the SBE 25.

Note: SEASOFT presents temperature, conductivity, and other variables as a function of depth or pressure, so the CTD's pressure resolution limits the number of plotted data points in the profile. For example, a CTD with a 10,000-psia sensor might acquire several values of temperature and conductivity during the time required to descend from 1- to 2-meters depth. However, all the temperature and conductivity values will be graphed in clusters appearing at either 1- or 2-meters on the depth axis.

ACCURACY CONSIDERATIONS USING HIGH-RANGE SENSORS IN SHALLOW WATER

High-range sensors used in shallow water will generally provide better accuracy than their *absolute* specifications would indicate. With careful use, they may exhibit *accuracy* approaching their *resolution* limits. For example, a 3000-psia sensor has a nominal accuracy (irrespective of actual operating depth) of ±3 meters. Most of the error, however, derives from variation over time and temperature of the sensor's *offset*, while little error occurs as a result of changing *sensitivity*. Furthermore, only the *offset* is of real significance in shallow-water applications (by definition *sensitivity* error cannot be greater than 0.15%, and thus the contribution to total error from this source cannot be greater than 0.15% of *reading*).

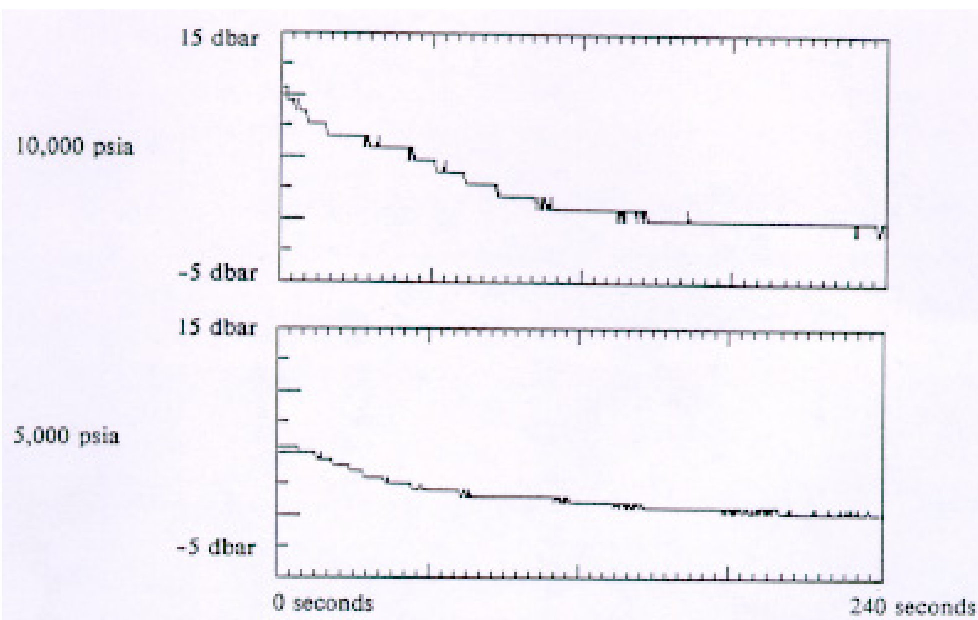
The primary *offset* error due to drift over time can be eliminated by letting the CTD take some readings in air before beginning the profile (if your CTD has a high-range -- 3000 psia or more --pressure sensor, wait 2 minutes before taking the *in air* reading; see the discussion under *TURN-ON TRANSIENTS* below). The pressure value indicated is the *offset* and can be eliminated by making an entry in the configuration (.con or .xmlcon) file of equal magnitude and opposite sign; the same data subsequently reevaluated with SEASOFT will then show an *in air* reading of 0 pressure.

The second source of *offset* error is temperature-induced drifts. These can be estimated for the conditions of the profile by observing the pre- and post-cast *in air* readings and using their mean value in the configuration (.con or .xmlcon) file. Because Paine sensors are carefully temperature compensated, errors from this source will be small. *Hysteresis* describes the failure of pressure sensors to repeat previous readings after exposure to other (typically higher) pressures. Hysteresis errors rise sharply as the sensor’s upper pressure limit is approached, and are very small when only the low end of the pressure range is in use.

Note: In our SEASOFT V2 suite of programs, edit the CTD configuration (.con or .xmlcon) file using the Configure Inputs menu in Seasave V7 (real-time data acquisition software) or the Configure menu in SBE Data Processing (data processing software).

TURN-ON TRANSIENTS

Sensors with 3000-, 5000-, 10,000- and 15,000-psia ranges exhibit a turn-on transient caused by self-heating of their internal bridge resistors. The transient lasts for approximately 2 minutes, as indicated by the plots below. The plots show the character of the turn-on transient for 5000- and 10,000-psia sensors. Note also the CTD’s pressure resolution limits, which can be seen in the step-wise change in pressure readings. The transient has a magnitude of about 10 dbar (10,000-psia sensor) and 5 dbar (5,000-psia sensor), approximately 0.15% of full scale range in both cases. This proportionality is maintained in all sensors observed to date. Because of their different internal construction, the turn-on transient is negligible in sensors with ranges of 1500-psia and below.



During calibration, the sensors are allowed to *warm-up* before calibration points are recorded. Similarly, for best depth accuracy the user should allow the CTD to *warm-up* for about 2 minutes before beginning a profile; this can be part of the *soak* time in the surface water. *Soaking* also allows the CTD housing to approach thermal equilibrium (minimizing the housing’s effect on measured temperature and conductivity) and permits a Beckman- or YSI-type dissolved oxygen sensor (if present) to polarize.