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APPLICATION NOTE 27 **SEPTEMBER 2001**

Minimizing Strain Gauge Pressure Sensor Errors

Sea-Bird's SBE 19 SEACAT Profilers (not 19*plus*), SBE 29 Strain-Gauge Pressure Sensors and SBE 25 SEALOGGER CTDs (built prior to March 2001), SBE 37 MicroCATs and SBE 39 Temperature Recorders (built prior to September 2000), and some SBE 16 SEACATs (not 16*plus*) used strain gauge pressure sensors manufactured by Paine Corporation, Seattle, Washington. These sensors offer accuracies of 0.25% (100 - 1500 psia units) and 0.15% (3000 - 15,000 psia units).

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 Corporation 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. 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. SEASOFT subtracts 14.7 psi from this reading and converts the remainder to dbar.

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

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 which is correct within 3% for almost all combinations of salinity, 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 the 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 in the instrument configuration (.con) file is used to estimate the magnitude of the local gravity field. For fresh water applications, compressibility is not significant in the shallow depths encountered and is ignored, 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).

Note: The CTD configuration (.con) file is edited using the Configure menu (in SEASAVE or SBE Data Processing in our SEASOFT-Win32 suite of programs) or SEACON (in SEASOFT-DOS).

CHOOSING THE RIGHT SENSOR

For best accuracy and resolution, a pressure sensor full scale range should be chosen to correspond to no more the greatest depths to be encountered. The implication of this choice in terms of CTD accuracy and resolution specifications is tabulated below:

Range (psia)	Depth (meters)	Maximum Error (meters)	Resolution (meters)
100	60	0.2	0.01
300	200	0.5	0.03
500	340	0.9	0.05
1,000	680	1.7	0.10
1,500	1,020	2.5	0.15
3,000	2,000	3.0	0.30
5,000	3,400	5.1	0.50
10,000	6,800	10.2	1.00
15,000	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 psi 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. 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 CTD's A/D converter, which 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 19 and SBE 25.

IMPORTANT: SEASOFT (and other CTD software) present temperature, salinity, 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 salinity during the time required to descend from one to two meters depth. However, all the T - S values will be graphed in clusters appearing at either one or two 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 psi or more --pressure sensor, wait two 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 nulled out by making an entry in the configuration (.con) file of equal magnitude and opposite sign; the same data subsequently reevaluated with SEASOFT will then show an *in air* reading of zero pressure.

The second source of *offset* error results from temperature-induced drifts. These can be estimated for the conditions of your profile by observing the pre- and post-cast *in air* readings and using their mean value in the .con file. Because Paine sensors are carefully temperature compensated, errors from this source will be small. *Hysteresis* is the term used to describe 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.

TURN-ON TRANSIENTS

Sensors with ranges of 3000, 5000, 10,000 and 15,000 psia 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 of pressure verses time for 5,000 and 10,000 psia sensors. Notice that the transient has a magnitude of about 10 dbar (10,000 psia sensors) and 5 dbar (5,000 psia sensor), which is about 0.15% of full scale range in both cases. This proportionality has been 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 two 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 (which will minimize the housing's effect on measured temperature and conductivity) and permits a Beckman- or YSI-type dissolved oxygen sensor (if present) to polarize. The plots below show the character of the turn-on transient for 10,000 and 5000 psia sensors. Note also the CTD's pressure resolution limits, which can be seen in the step-wise change in pressure readings.