CALIBRATION PROCESS FOR CTD (Conductivity, Temperature and Depth)

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Abstract: Detailed herein is the procedure to perform the calibration of a marine observation instrument, in this case a CTD, within the parameters of temperature, pressure and conductivity. It includes a calibration demonstration of the temperature and the pressure parameters.

Key words: CTD, calibration, temperature, pressure, conductivity

1. INTRODUCTION

Research in the marine field is currently at its peak, as monitoring the sea surface via satellite and with specific measuring instruments [1], as permanent marine research stations are being installed at the sea bottom [2-4]. The CTD is a robust piece of equipment commonly used on those oceanographic campaigns and observation platforms.

CTDs measure the temperature, the pressure and the conductivity of the sea at different depths, and are a key instrument for determining important physical properties of the water. They provide to the scientists a clear picture of the distribution and changes of the water temperature, the salinity and density that helps to study how oceans are related to life. In order to provide reliable data when interpreting the results in scientific campaigns, or for use in the private sector, a regular calibration is mandatory.

The purpose of this article is to propose a calibration method for the CTD instrument for the parameters of pressure, temperature and conductivity, even though only temperature and pressure are put into practice here. On Section 2, we describe the proposed calibration method. On Section 3 results are commented and the final section contains the conclusions.

2. CALIBRATION METHOD

2.1. System Description:

The elements used for temperature calibration are shown in Figure 1, and consist of:

- Climate chamber

- Standard thermometer (2 units)

Fig. 1. Calibration system for temperature

On the other hand, the elements used for the pressure calibration are shown in Figure 2, and consist of:

- Hyperbaric chamber
- Standard pressure sensor
- Standard thermometer

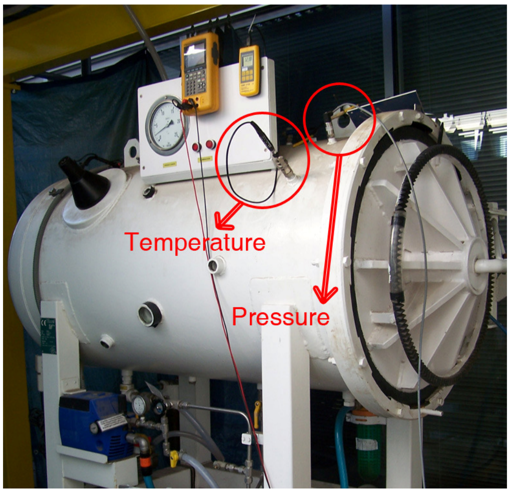

Fig. 2. Calibration system for pressure

Liquid samples with a known conductivity and its associated traceability are used for conductivity tests.

2.2. Temperature calibration procedure

To perform the temperature calibration, 5 temperature points within the useful range of the CTD were analyzed. The process followed consists on starting at the lowest temperature and then increase it up to the measurement points that have been established. Once the maximum has been reached, return to the initial point. In the case of the temperature, the hysteresis and the repeatability have also been analyzed. The cycle of hysteresis consists on fixing a reference temperature contained in the range of use of the instrument. Once this is done, carry out cycles formed by warming to the maximum point, then cool it down until reaching the minimum temperature point, and finally raise the temperature again to reach the reference temperature. This cycle must be carried out three times.

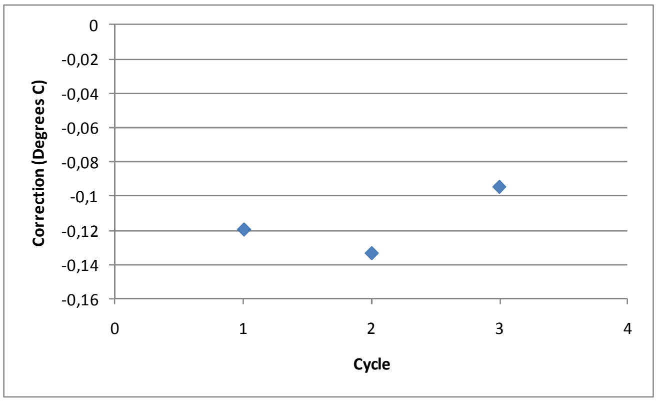

Fig. 3. Results from the hysteresis analysis

For the temperature, we find a value for the reference temperature as well as for the correction within its respective uncertainty. In equations (1) and (2), we can see the calculation of the reference temperature and that of the correction. In equations (3) and (4), we can see the uncertainty budget of the reference temperature and that of the correction found respectively according to the methodology provided on [5].

$$t_{ref} = \frac{1}{2}(t_1 + \delta t_{c1} + \delta t_{d1} + \delta t_{1,res} + \\ + \delta t_{1,mi} + \delta t_{1,int} + t_2 + \delta t_{c2} + \delta t_{d2} + \\ + \delta t_{2,res} + \delta t_{2,mi} + \delta t_{2,int}) + \delta t_u + \delta t_e \quad (1)$$

where,

t_i is the reference temperature of the reference thermometer i (i=1,2)

$t_{i,c}$ is the correction of the reference thermometer i (i=1,2)

$t_{i,d}$ is the drift of the reference thermometer i (i=1,2)

$t_{i,res}$ is the resolution of the reference thermometer (i=1,2)

$t_{i,mi}$ is the correction of the reference thermometer by influence magnitudes (i=1,2)

$t_{i,int}$ is the correction of the reference thermometer by the interpolation's error of the results of the thermometer certificate i (i=1,2)

t_u is the uniformity

t_e is the stability

$$C = t_{ref} - (t_x + \delta t_{x,res} + \\ + \delta t_h + \delta t_{un} + \delta t_r + \delta t_{x,mi}) \quad (2)$$

where,

C is the correction temperature at CTD

t_x is the measured temperature

t_{xres} is the instrument resolution

t_h is the hysteresis process

t_{un} is the uniformity of the environment

t_r is the process repeatability

$t_{x,min}$ is the correction by the magnitudes influence

$$u^2(t_{ref}) = \frac{1}{4}(u^2(t_1) + u^2(t_2) + \\ + u^2(\delta t_{c1}) + u^2(\delta t_{c2}) + u^2(\delta t_{d1}) + \\ + u^2(\delta t_{d2}) + u^2(\delta t_{1,res}) + \\ + u^2(\delta t_{2,res}) + u^2(\delta t_{1,mi}) + u^2(\delta t_{2,mi}) + \\ + u^2(\delta t_{1,int}) + u^2(\delta t_{2,int})) + \\ + u^2(\delta t_u) + u^2(\delta t_e) \quad (3)$$

where,

u (j) is the contribution to the uncertainty of the component j. The contributions have a rectangular probability distribution: $u(t_{i,c})$, $u(t_{i,d})$, $u(t_{i,res})$, $u(t_e)$, $u(t_u)$, $u(t_{i,mi})$

$u(t_i)$ is the contribution obtained from the calibration certificate. This contribution is normal and the factor coverage (k) value is known, i=1,2

$u(t_{i,int})$ is a curve that we obtain with the calibration certificate . i=1,2

$$u^2(C) = u^2(t_x) + u^2(\delta t_{x,res}) + u^2(\delta t_h) + \\ + u^2(\delta t_{un}) + u^2(\delta t_{x,mi}) + u^2(\delta t_r) + u^2(t_{ref}) \quad (4)$$

u (j) is the contribution of the uncertainty of the component j. The contributions that follow a probability distribution are: $u(t_h)$, $u(t_{un})$ and $u(t_r)$.

$u(t_{xres})$ and $u(t_{x,mi})$ are rectangular probability distributions

$u(t_x)$ is the uncertainty of the thermometer.

$u(t_{ref})$ is detailed on (3)

2.3. Pressure calibration procedure

In the case of the pressure sensor, we select 5 measurement points between the 10% and 100% of its range of work. In this case we perform two cycles, each starting at an initial point, until the final point is reached. Once such final point is exceeded, the process is inverted until the starting point is reached. The performance of one cycle gives us 2 measurements for each measurement point. The calculation of the contributions for the determination of the correction is detailed in equation (5), and the assessment of the uncertainty budget of the correction is detailed in equation (6), found according to the methodology described on [5]. In this case, the determination of the expanded measurement uncertainty is calculated using equation (9).

$$C_i = P_{Ri} - P_{Xi} + \sum_j \delta_j(Pat) + \sum_k \delta_k(Ins) + \Delta_{NR} \tag{5}$$

where:

P_{Ri} is the value of reference at point i

P_{Xi} is the value of device at point i

Pat is the sum of the different corrections of the references (calibration, drift and temperature corrections)

Ins is the sum of the different corrections of the device (Resolution, temperature and hysteresis)

Δ_{NR} is the correction due to the height difference between reference position and the device

$$u(C_i) = \sqrt{u(patro)^2 + u(der)^2 +} \sqrt{+u(t,pat)^2 + u(res)^2 + u(t,ins)^2 +} \sqrt{+u(his)^2 + u(rep)^2 + u(\Delta_{NR})^2} \tag{6}$$

where,

u(X) is the contributions of the uncertainty of the component X. For all cases we detail the probability distribution:

u(patro) has normal probability distribution, we know the uncertainty value and coverage factor with the calibration certificate.

The contributions that have a rectangular probability distribution are: *u(der)*, *u(t,pat)*, *u(res)*, *u(t,ins)*, and *u(his).*

u(rep) is the repeatability contributions and it has a contribution of type A, detail on (7)

$u(\Delta_{NR})$ is the contribution to the uncertainty between the reference and the device. This value is detail in (8), which is the result of the partial derivate of the error propagation.

$$u(rep) = \frac{1}{\sqrt{n}} \cdot s = \frac{1}{\sqrt{n}} \cdot \sqrt{\frac{\sum_{i=1}^{n}(P_i - \bar{P_i})^2}{n-1}} = \frac{1}{\sqrt{n}} \cdot \sqrt{\frac{\sum_{i=1}^{n}\left(P_i - \frac{\sum_{i=1}^{n} P_i}{n}\right)^2}{n-1}} \tag{7}$$

$$u(\Delta_{NR}) = \pm(\rho_f - \rho_a) \cdot g_l \cdot u(h) \tag{8}$$

$$U = U_{i,max} + |C_{max}| \tag{9}$$

2.4. Conductivity calibration procedure

The conductivity calibration is calculated using solutions with a known conductivity, traceable to an accredited body. The calibration has to be performed at the reference temperature marked on the bottle, which is typically 25ºC. During calibration, the following parameters are measured: the resistance, the temperature of the environment, and the conductivity that marks the equipment under test. Also, 5 measurement points within the range of work of the equipment under test will be chosen. Each of the points will be measured once, except for 1 point where 10 measurements will be performed.

The components used in the calculation are detailed in equation (10).

$$u^2 = u(rep)^2 + u(pat)^2 + u(res)^2 + u(t)^2 \tag{10}$$

where:

u(rep) is the repeatability contribution and it has a Gaussian probability distribution.

u(pat) is the master contribution and it has a Gaussian distribution with the parameter that we get from the calibration certificate.

u(res) is the resolution contribution and it has a rectangular probability distribution.

u(t) is the temperature contribution and it gets its value from a normal and a rectangular probability distribution. The first one comes from the calibration certificate, and the other is the deviation at 25 Celsius degree.

3. RESULTS

We present the values found through the calibration systems for temperature and for pressure.

3.1. Results for temperature calibration:

Once the calibration procedure has been performed, the different uncertainty contributions are calculated, shown in Table 1.

Table 1. Components of the uncertainty contribution

Parameter	Unit (°C)
u(resCTD)	0,000029
u(t1)	0,002500
u(t2)	0,002500
u(δtd1)	0,028868
u(δtd2)	0,028868
u(δtres1)	0,002887
u(δtres2)	0,002887
u(δtr)	0,016696
u(δth)	0,022228

The numerical result of the procedure detailed system in Section 2.2 is shown in Figure 4.

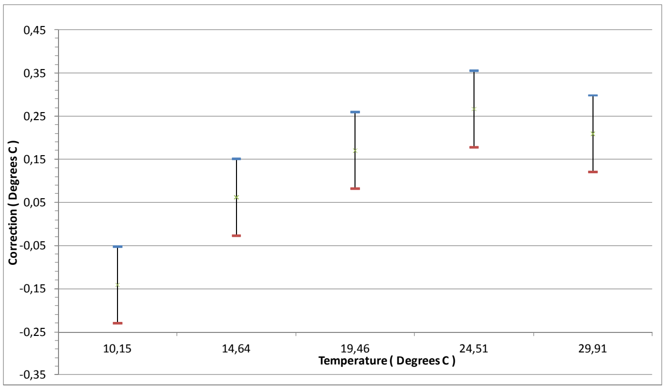

Fig. 4. Graph of the correction values with their expanded measurement uncertainty

3.2. Results for pressure calibration:

The numerical results of the procedure detailed on Section 2.3 are shown on Table 2:

Table 2. Results for the pressure calibration

First cycle				
Nominal (dbar)	Nominal (mA)	T_{UP} (ºc)	T_{DOWN} (ºc)	Histeris (dbar)
15	4,5	12,15	12,22	-0,144
20	4,75	12,15	12,21	-0,032
25	5	12,17	12,21	-0,124
30	5,25	12,18	12,2	-0,1
40	5,5	12,19	12,19	-0,44
Second cycle				
Nominal (dbar)	Nominal (mA)	T_{UP} (ºc)	T_{DOWN} (ºc)	Histeris (dbar)
15	4,5	12,22	12,28	-0,284
20	4,75	12,24	12,28	0,018
25	5	12,25	12,28	0,015
30	5,25	12,25	12,27	0,031
40	5,5	12,25	12,25	0,031

The uncertainty contributions for each of the components are detailed on Figure 5.

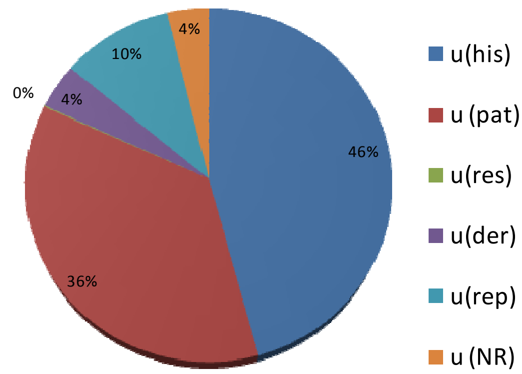

Figure 5. Component's contributions uncertainty

Finally we determinate the expanded uncertainty measurement including the correction value, Equation (9):

$$U\ (k=2) = 0{,}770\ \text{dbar} = 77\ \text{kPa}$$

The uncertainty value found here is large, of about 1 m of water column. As it is shown in Figure 5, in order to improve this uncertainty value, a master reference with a smaller uncertainty is required.

4. CONCLUSION

We have presented a calibration procedure for a CTD, where the uncertainties associated to the measurement of different parameters have been detailed. With this proposed method, the reliability and traceability on the measurements carries out by the CTD are improved. The method has been tested using real data from a CTD for the parameters of temperature and pressure.

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