国家海洋标准计量中心
National Center Of Ocean Standards And Metrology

CTD Pressure Sensor Calibration

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Outline

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3. CTD pressure sensor calibration
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Tianjin

1. Overview

Affiliation

- NCOSM, located in Tianjin, is one of the institutions directly under the Ministry of Natural Resources of China(MNR).
- NCOSM is a legal metrological verification institution authorized by the State Administration for Market Regulation (SAMR) of China.
- As a part of NCOSM,**CTD Calibration Facility** has been providing calibration services since 1988.It provides calibration services for thousands of CTD instruments every year.

1. Overview

CTD Calibration

- Modern sensors and transmitters are electronic devices that employ electrical signals such as voltage and current, which naturally drift over time.
- Calibration of the CTD is important to the quality of the measurement data.

Pressure (Depth)

Range:	20 / 50 / 100 / 200 / 500 / 740 / 1000 / 2000m (dBar)
Accuracy:	±0.05% full scale at T=20°C ±0.10% with temperature correction
Resolution:	<0.001% full scale
Time Constant:	<0.01s
Drift:	~0.2%/year

1. Overview

Capabilities

- The facility calibrates a wide range of oceanographic instrumentation to a level of accuracy consistent with the world's best practice.

Certificates for Examination of Measurement Standards

Measurement Standard	Range	MPE
Temperature (℃)	-2～40	±0.002
Salinity	2～42	±0.001
Pressure (MPa)	0.05～100	±0.005%

- All Temperature & Pressure metrology standards could be traced to a higher level of measurement authority (e.g. NIM，China National Institute of Metrology) ,and SI units traceable.
- Salinity could be traced to PSS-78.

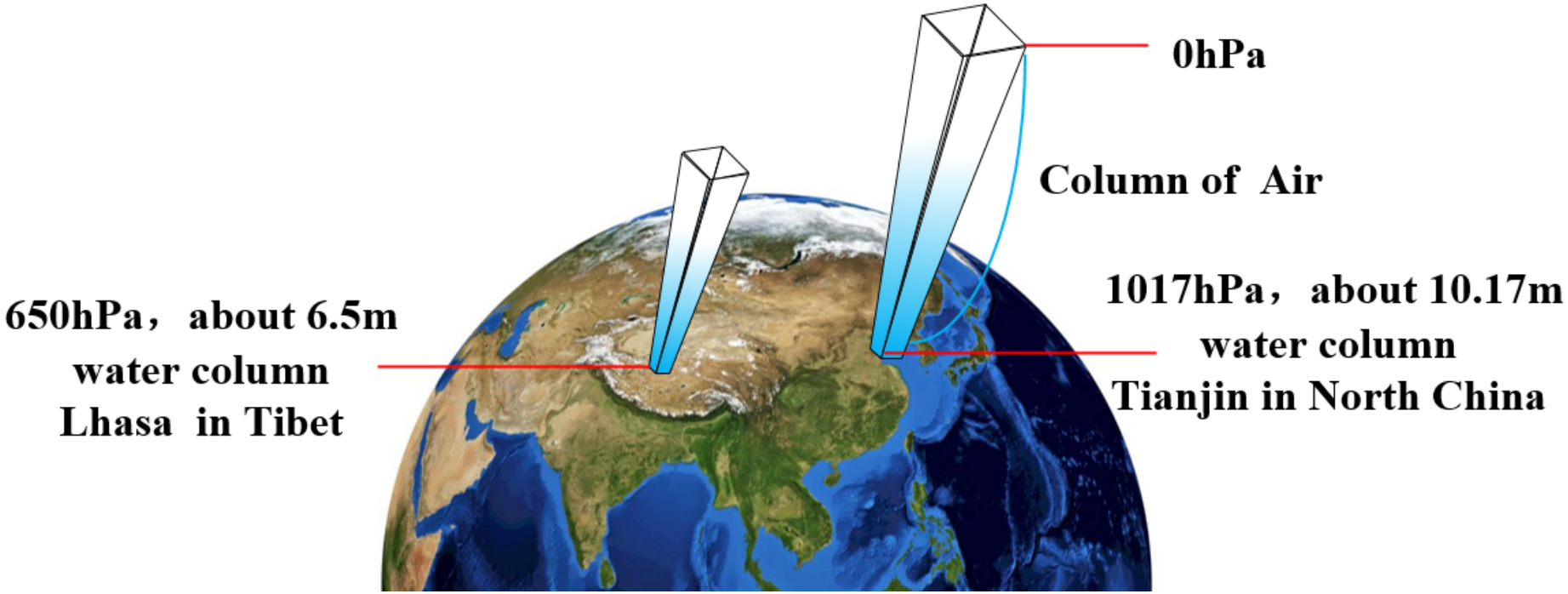
2. Background Knowledge

2.1 Pressure units

- The units of pressure are usually expressed in Pa , hPa , kPa , MPa , psi , dbar , water column (mm\cm\m), etc.

2.2 Atmospheric, absolute and gauge pressures

1atm=1013.25hPa≈0.1MPa ≈10m water

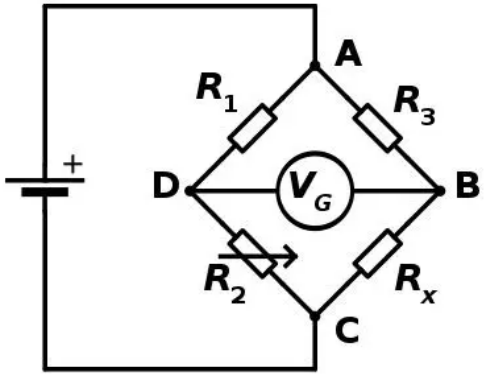


2. Background Knowledge

2.3 Marine Pressure Sensors

2.3.1 Principle

- The main pressure sensors used in marine instruments are "silicon piezoresistive pressure sensors" and "resonant pressure sensors" (e.g., Paros' quartz resonant pressure sensors).

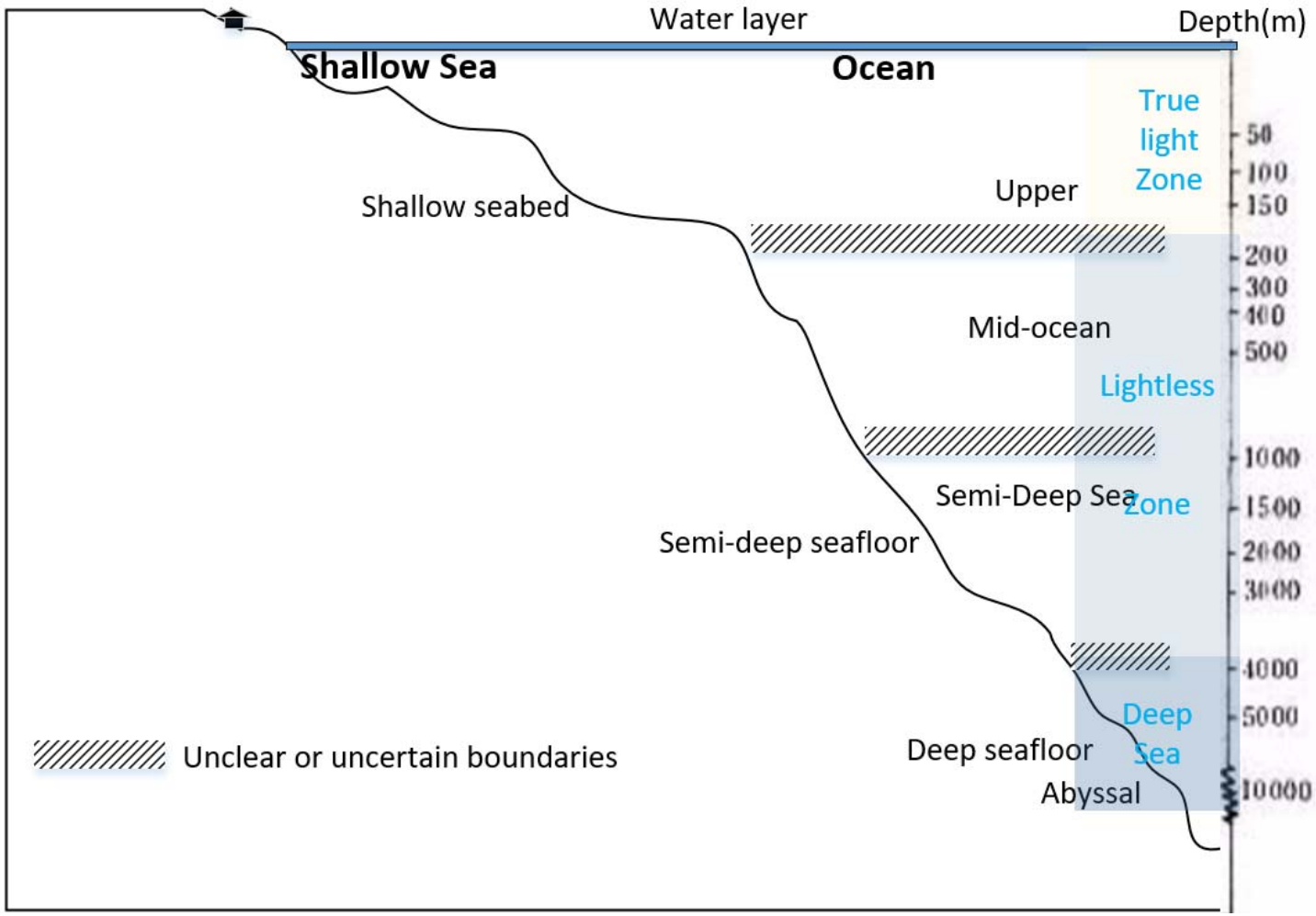


2.3.2 Range

- Pressure sensor range: 0~10,000m (0-100MPa).
- Note, that except for trenches, the vast majority of the world's oceans do not exceed 6000m in depth.

2. Background Knowledge

2.3 Marine Pressure Sensors



2. Background Knowledge

2.3 Marine Pressure Sensors

2.3.3 Accuracy

- CTD pressure sensor (common technical specifications are: 0.3%FS, **0.1%FS**, **0.05%FS**, 0.02%FS, 0.015%FS, 0.01%FS).
- Most pressure sensors used on CTDs have a maximum allowable error of 0.1% FS or 0.05% FS.

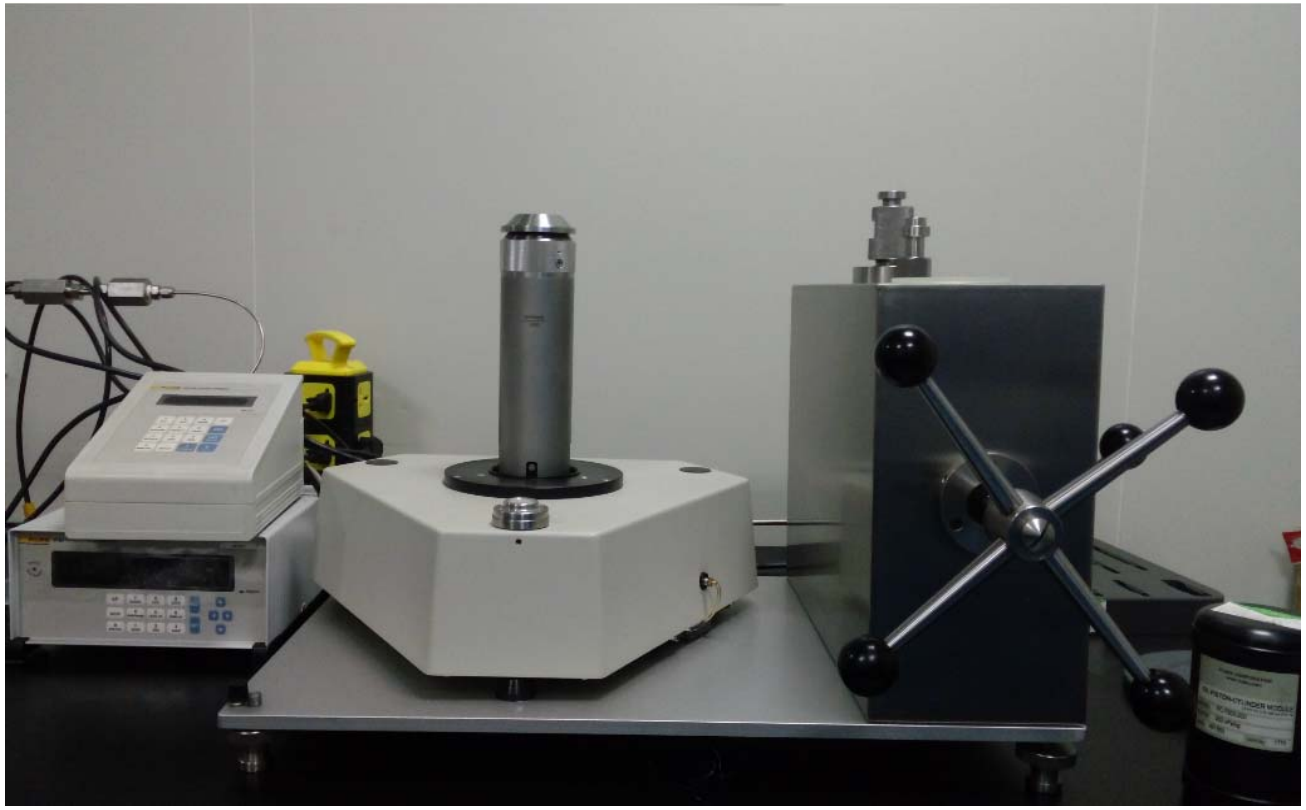
2.3.4 Pressure and Depth Conversion

- The formula for converting pressure to depth is usually built into the CTD instrument or its dedicated software by the manufacturer (e.g. Sea Bird and RBR).
- SEE:*Algorithmsfor the computation of fundamental properties of seawater*， by NP Fofonoff · 1983. UNESCO Technical Papers in Marine Sciences; 44

3. CTD pressure sensor calibration

3.1 Selection of pressure standard

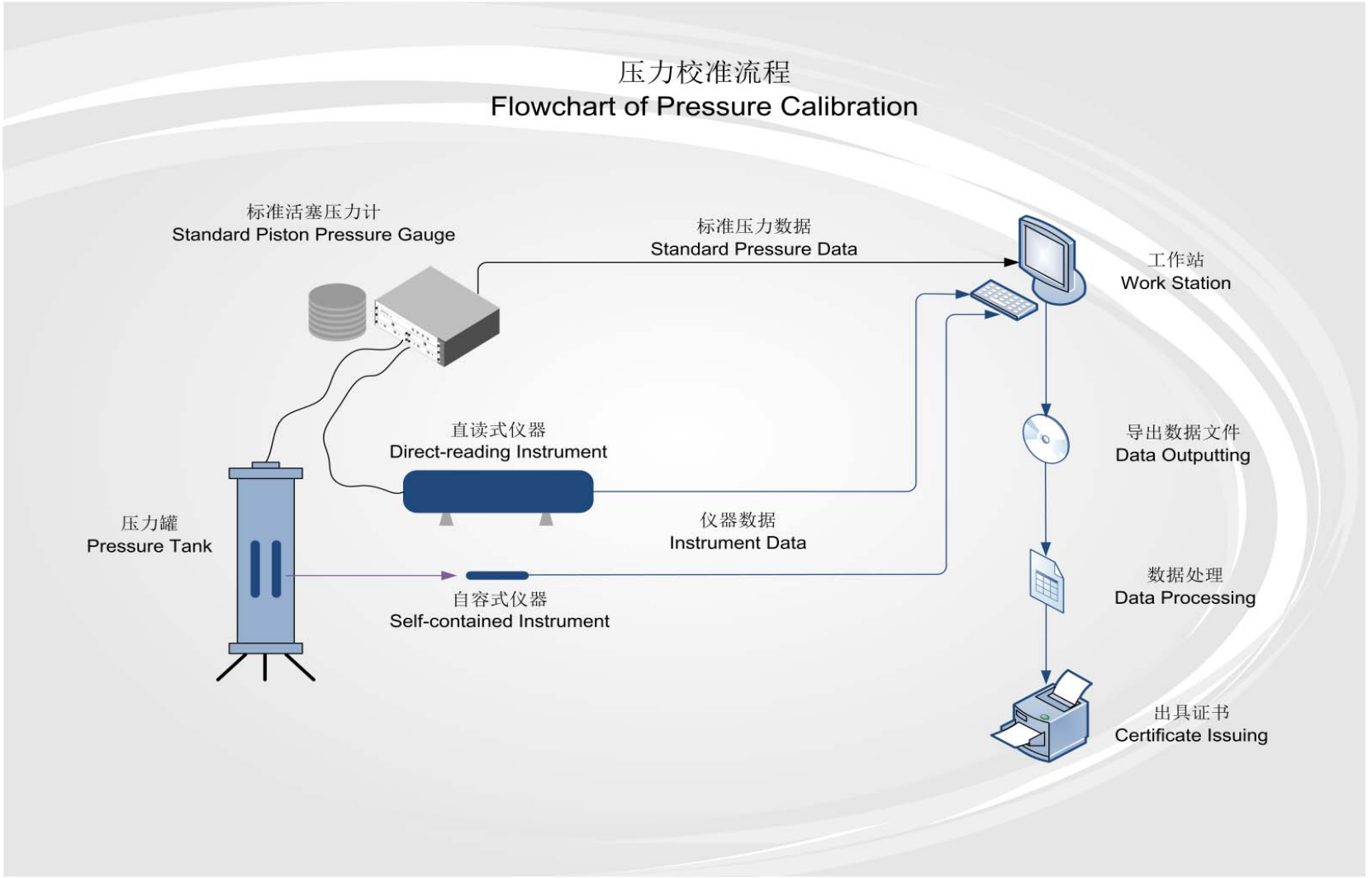
- Pressure standard selection requirements: the accuracy level of the standard is at least 3 times the relationship of the Device Under Test(DUT)



The Fluke PG7302 Piston Gauge in NCOSM.

3. CTD pressure sensor calibration

3.2 The pressure calibration process



3. CTD pressure sensor calibration

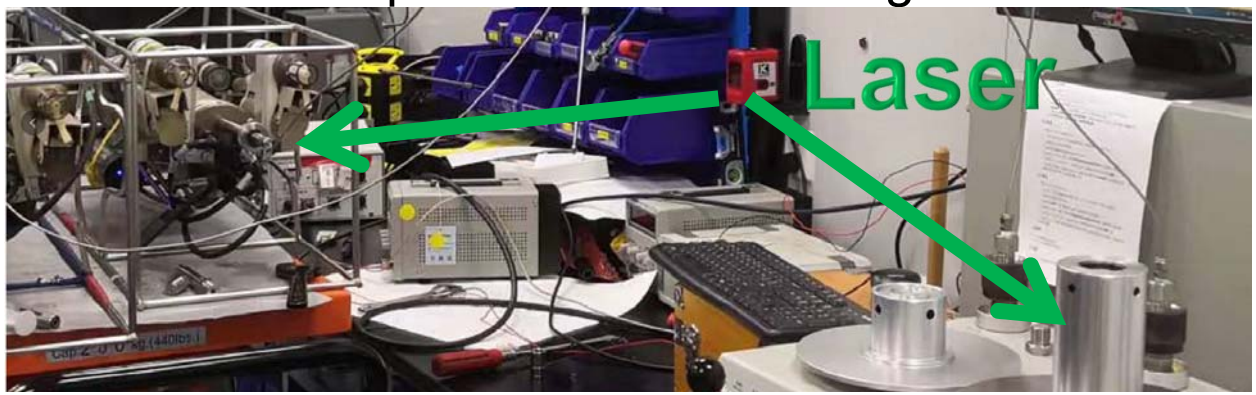
3.3 Operation steps

Pressure Sensor Calibration Lab

3. CTD pressure sensor calibration

3.3 Operation steps

- **Step1**. Keep the Pressure Standard and DUTs in a constant temperature laboratory at a temperature of (20±1)℃ for 2h-4h or more, so that their temperatures reach to temperature balance, and ,open the power of the DUT for sufficient preheating.
- **Step2.** The CTD will first be placed on the bench, refer to the laser level, adjust the lifting platform so that the CTD pressure sensor position as far as possible with the reference position of the pressure standard , the pressure standard and CTD pressure sensor connected. Pressure calibration points in the CTD pressure range evenly selected not less than 7 points. The pressure calibration preccess should follow the sequence of ascending first and then descending.



3. CTD pressure sensor calibration

3.3 Operation steps

- **Step3.** After stabilization at each pressure calibration point, the CTD measurement data should be no less than 10 groups, and the arithmetic mean should be taken as the pressure indication value.
- **Step4.** Calculate the indicated value error according to the following formula.

$$\Delta p_i = p_i - p_{is} \tag{1}$$

Δp_i - the pressure error of the CTD at the i-th pressure calibration point, Pa.

p_i - the pressure indication value of the CTD at the i-th pressure calibration point, Pa.

p_{is} - the standard pressure value of the i-th pressure calibration point, Pa.

Take the absolute value (MPEV) of the largest ΔPi as the CTD pressure indication error.

3. CTD pressure sensor calibration

3.3 Operation steps

- **Step5.**Repeatability: The pressure measurement repeatability selects the calibration point with the largest pressure value and repeats step 2 to complete 6 measurements, and the pressure standard needs to be rebalanced after each measurement before the next measurement.
- **Step6.**Calculate the pressure measurement repeatability based on equation (2).

$$\sigma_p = \sqrt{\frac{\sum_{i=1}^{n}(p_i - \bar{p})^2}{n-1}} \tag{2}$$

σ_p - CTD pressure measurement repeatability, Pa.

p_i - the CTD pressure value at the i-th measurement, Pa.

$\bar{p}$ - arithmetic mean of CTD at n measurements, Pa.

n- number of measurements (n=6).

3. CTD pressure sensor calibration

3.4 Data processing

- Pre-process, clean and organize the standard pressure data and the data of the DUT to obtain the format of the original data suitable for issuing the certificate.
- Compare the calibrated instrument data with the standard pressure data and calculate the error of the displayed value.
- If the initial indicated value error of the DUT is large, it is recommended in principle to fit the standard value to the original value of the DUT according to the factory calibration formula of the DUT, fit a new coefficient, and give the new coefficient to the customer.
- The figure below shows the factory calibration page of an SBE37. When new coefficients are to be given to the DUT, the "raw" data of the DUT should be obtained and fitted to the standard pressure values using the least squares method.

3. CTD pressure sensor calibration

3.4 Data processing

COEFFICIENTS:

PA0 =	2.067221e-001	PTCA0 =	1.008463e+002
PA1 =	1.405210e-001	PTCA1 =	6.665711e-002
PA2 =	-4.010489e-008	PTCA2 =	-3.560296e-007
PTHA0 =	-6.818419e+001	PTCB0 =	2.548725e+001
PTHA1 =	5.150212e-002	PTCB1 =	1.250000e-003
PTHA2 =	-2.600325e-007	PTCB2 =	0.000000e+000

PRESSURE SPAN CALIBRATION

PRESSURE PSIA	INST OUTPUT	THERMISTOR OUTPUT	COMPUTED PRESSURE	ERROR %FSR
14.63	205.2	1768.9	14.65	0.00
591.53	4320.8	1770.8	591.63	0.00
1168.48	8446.4	1771.8	1168.66	0.01
1745.54	12581.7	1773.2	1745.67	0.00
2322.45	16725.6	1774.0	2322.51	0.00
2899.18	20878.4	1774.8	2899.20	0.00
2322.46	16724.6	1774.2	2322.37	-0.00
1745.77	12581.4	1773.5	1745.63	-0.01
1168.57	8445.0	1773.3	1168.46	-0.00
591.53	4318.9	1773.0	591.36	-0.01
14.63	205.0	1773.1	14.62	-0.00

THERMAL CORRECTION

TEMP ITS90	PRESS TEMP	INST OUTPUT
32.50	1974.20	211.47
29.00	1906.00	211.43
23.99	1806.20	211.16
18.50	1697.80	210.60
15.00	1628.00	210.28
4.50	1422.00	209.77
1.00	1352.30	209.47

TEMP(ITS90)	SPAN(mV)
-5.00	25.48
35.00	25.53

y = thermistor output; $t = PTHA0 + PTHA1 * y + PTHA2 * y^2$

x = pressure output $- PTCA0 - PTCA1 * t - PTCA2 * t^2$

$n = x * PTCB0 / (PTCB0 + PTCB1 * t + PTCB2 * t^2)$

pressure (psia) $= PA0 + PA1 * n + PA2 * n^2$

3. CTD pressure sensor calibration

3.4 Data processing

The comparison of the indicated value error of an SBE16plus before and after calibration.

数据计算

压力

原始数据 Nominal

	砝码压力值	标准压力值	仪器N值	标准PSI	初始示值	初始误差	拟合示值	示值误差
	Standard Pressure (dbar)		Pressure Raw Data (counts)	Standard Pressure (psia)	Pressure Indication (dbar)	ERROR Before (dbar)	Pressure Calculated (dbar)	ERROR After (dbar)
1	0.00	-0.14	487	14.496947217...	-2.01	-1.87	-0.20	-0.06
2	500.00	499.86	24416	739.68545634...	496.86	-3.00	499.43	-0.43
3	1000.00	999.86	48282	1464.8739654...	996.18	-3.68	999.37	-0.49
4	2000.00	1999.86	95783	2915.2509837...	1995.15	-4.71	1999.23	-0.63
5	3000.00	2999.86	143005	4365.6280019...	2995.13	-4.73	2999.60	-0.26
6	4000.00	3999.86	189921	5816.0050202...	3995.40	-4.46	3999.78	-0.08
7	5000.00	4999.86	236525	7266.3820384...	4995.71	-4.15	4999.52	-0.34
8	4000.00	3999.86	189951	5816.0050202...	3996.04	-3.82	4000.42	0.56
9	3000.00	2999.86	143041	4365.6280019...	2995.89	-3.97	3000.37	0.51
10	2000.00	1999.86	95827	2915.2509837...	1996.08	-3.78	2000.16	0.30
11	1000.00	999.86	48317	1464.8739654...	996.90	-2.96	1000.10	0.24
12	500.00	499.86	24449	739.68545634...	497.56	-2.30	500.12	0.26
13	0.00	-0.14	510	14.496947217...	-1.54	-1.40	0.28	0.42

Before

After

修约: 6 位差(m): 0 绝压 位差 自动 人工 0.20

拟合曲线

拟合系数

科学计数法 6 不确定度: 0.02% 使用拟合

y=-3.116222233466640E-001+3.023174433047600E-002*x+2.067093000000000E-009*x^2

PA0=-3.116222E-001
PA1= 3.023174E-002
PA2= 2.067093E-009

New Coefficients

3. CTD pressure sensor calibration

3.5 Uncertainty assessment

- According to the relevant international standards, the measurement uncertainty of CTD pressure calibration results is analyzed and evaluated, and there are mainly five factors as the sources of uncertainty of pressure calibration results.

- The standard uncertainty $u_1(p_y)$ introduced by the measurement repeatability of the DUT.
- The standard uncertainty component $u_1(p_x)$ introduced by the standard manometer.
- Standard uncertainty component introduced by ambient temperature fluctuations $u_2(p_x)$.
- Standard uncertainty component introduced by liquid column difference $u_3(p_x)$.
- Standard uncertainty introduced by the air zero $u_4(p_x)$.

- The calibration of a pressure sensor with a range of 50 MPa (5000 m) CTD with a claimed MPE of $\pm$0.1%FS is illustrated as an example. Uncertainty assessment process omitted. Taking the confidence probability p=95% and k=2, the extended uncertainty is *U*=2$\times$0.00403=0.00806 MPa, and the relative extended uncertainty *U*r=0.02%. Therefore, the relative extended uncertainty of the pressure calibration result is 0.02% with k=2.

4. Precautions

4.1 Gravitational acceleration values

- Gravitational acceleration in the laboratory should be obtained accurately. The gravitational acceleration g in the pressure laboratory was measured by NIM(The National Institute of Metrology,China), and this data has a non-negligible effect on the accuracy of the piston gauge, especially the 0.005 class piston gauge.

4.2 Pressure adapters

- Pressure adapters should be made to connect the standard to the DUT.

CTD Pressure Sensor Calibration in RMIC/AP

Thank You

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