Strain Gage measurements

M.Testa, M Beretta,

B. Buadze, Z. Chubinidze,

S. Serafino, G. Papalino

Strain Gage: Intro

Strain gage measure the strain

- $\varepsilon_i = \Delta L_i \ / \ L_i$
- $\Delta R_i \ / \ R_i = K \ \varepsilon_i$
- $K \sim 2$ is the gage factor
- $L_i \sim$ 7mm is the strain-gage length

$$\left(\frac{\Delta R}{R_0}\right)_{T/O} = \left[\beta_G + F_G\left(\frac{1+K_t}{1-\nu_0 K_t}\right)(\alpha_S - \alpha_G)\right]\Delta T \qquad (1)$$

where, in consistent units:

$\left(\frac{\Delta R}{R_0}\right)_{T/O}$ = unit change in resistance from the initial reference resistance, R_0, caused by change in temperature resulting in thermal output.

β_G = temperature coefficient of resistance of the grid conductor.

F_G = gage factor of the strain gage.†

K_t = transverse sensitivity of the strain gage.

ν_0 = Poisson's ratio (0.285) of the standard test material used in calibrating the gage for its gage factor.

TABLE 1—NOMINAL THERMAL EXPANSION COEFFICIENTS OF ENGINEERING MATERIALS

MATERIAL DESCRIPTION	EXPANSION COEFFICIENTS** Per °F	EXPANSION COEFFICIENTS** [Per °C]	RECOMMENDED S-T-C NUMBER
ALUMINA, fired	3.0	[5.4]	03
ALUMINUM Alloy, 2024-T4*, 7075-T6	12.9	[23.2]	13*
BERYLLIUM, pure	6.4	[11.5]	06
BERYLLIUM COPPER, Cu 75, Be 25	9.3	[16.7]	09
BRASS, Cartridge, Cu 70, Zn 30	11.1	[20.0]	13
BRONZE, Phosphor, Cu 90, Sn 10	10.2	[18.4]	09
CAST IRON, gray	6.0	[10.8]	06
COPPER, pure	9.2	[16.5]	09
GLASS, Soda, Lime, Silica	5.1	[9.2]	05
INCONEL, Ni-Cr-Fe alloy	7.0	[12.6]	06
INCONEL X, Ni-Cr-Fe alloy	6.7	[12.1]	06
INVAR, Fe-Ni alloy	0.8	[1.4]	00
MAGNESIUM Alloy*, AZ-31B	14.5	[26.1]	15*
MOLYBDENUM*, pure	2.7	[4.9]	03*
MONEL, Ni-Cu alloy	7.5	[13.5]	06
NICKEL-A, Cu-Zn-Ni alloy	6.6	[11.9]	06
QUARTZ, fused	0.3	[0.5]	00
STEEL Alloy, 4340	6.3	[11.3]	06
STEEL, Carbon, 1008, 1018*	6.7	[12.1]	06*
STEEL, Stainless, Age Hardenable (17-4PH)	6.0	[10.8]	06
STEEL, Stainless, Age Hardenable (17-7PH)	5.7	[10.3]	06
STEEL, Stainless, Age Hardenable (PH15-7Mo)	5.0	[9.0]	05
STEEL, Stainless, Austenitic (304*)	9.6	[17.3]	09*
STEEL, Stainless, Austenitic (310)	8.0	[14.4]	09
STEEL, Stainless, Austenitic (316)	8.9	[16.0]	09
STEEL, Stainless, Ferritic (410)	5.5	[9.9]	05
TIN, pure	13.0	[23.4]	13
TITANIUM, pure	4.8	[8.6]	05
TITANIUM Alloy, 6AL-4V*	4.9	[8.8]	05*
TITANIUM SILICATE*, polycrystalline	0.0	[0.0]	00*
TUNGSTEN, pure	2.4	[4.3]	03
ZIRCONIUM, pure	3.1	[5.6]	03

* Indicates type of material used in determining thermal output

Strain Gage: Methodology

In our samples thermal output vs T given for Steel 1018

$$\epsilon_{T/O} = \left(\frac{\beta_G}{F_G} - \alpha_G \right) \Delta T + \alpha_S \Delta T$$

$\varepsilon = \Delta L \;/\; L$

For Another material X:

$$\epsilon_X = \left(\frac{\beta_G}{F_G} - \alpha_G \right) \Delta T + \alpha_X \Delta T$$

- $\varepsilon_X - \varepsilon_{T/O} = (\alpha_X - \alpha_{steel})\ \Delta T$
  - The subtraction removes the thermal response of the strain gage and leaves just the part that depends on the substrate

- Measure ε_X as a function of T
- Fit $\varepsilon_X - \varepsilon_{T/O}$ vs T

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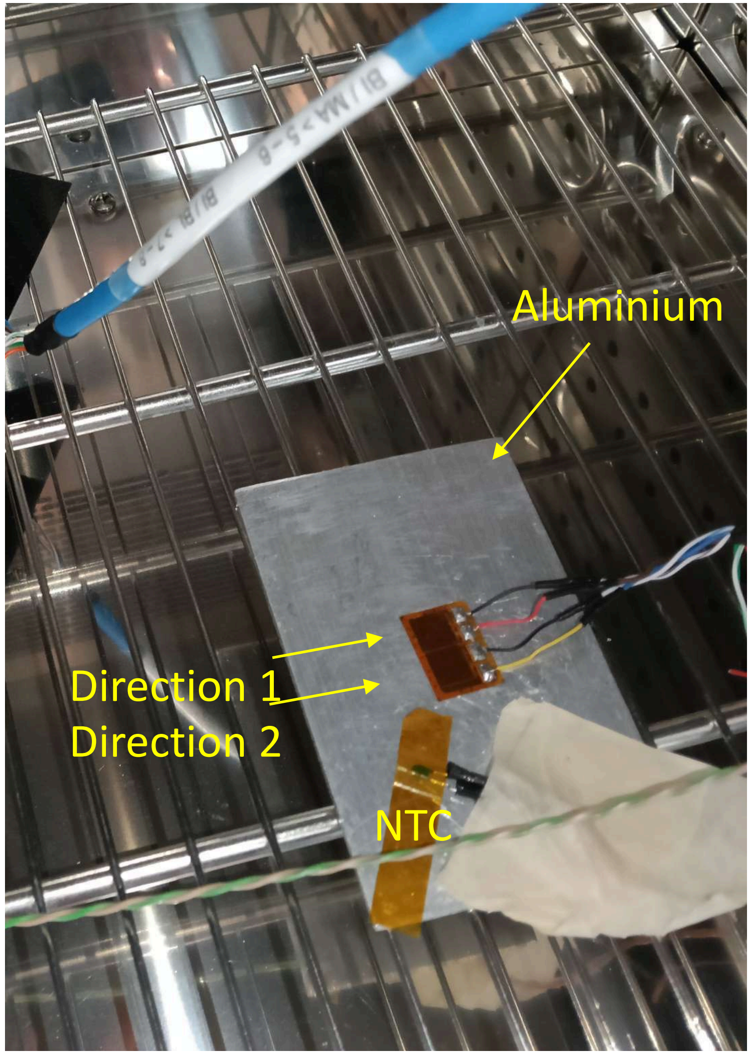
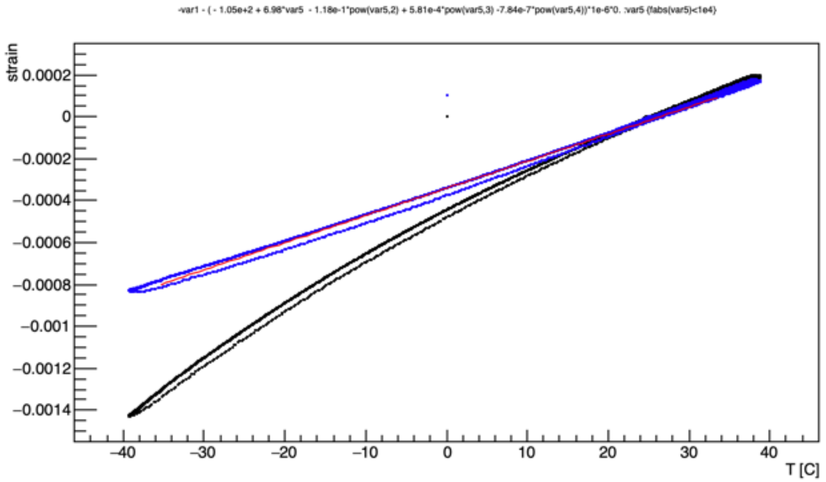
Experimental setup with Aluminium



The setup is inside a climate chamber

Blue points and Fit: : after thermal correction

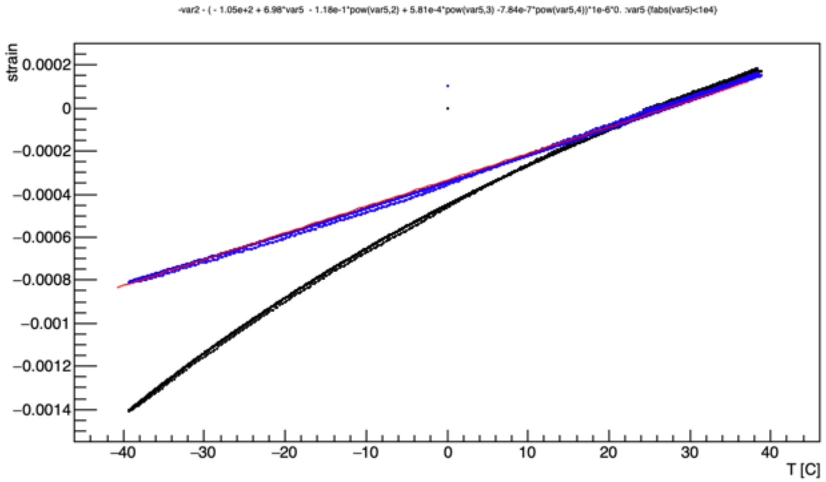
Strain-gage 1 Al



slope_measured ~ 13.0 e-6 / C

α_{Al} = slope_measured + α_{steel} ~ 25.1 e-6 / C

Strain-gage 2 Al

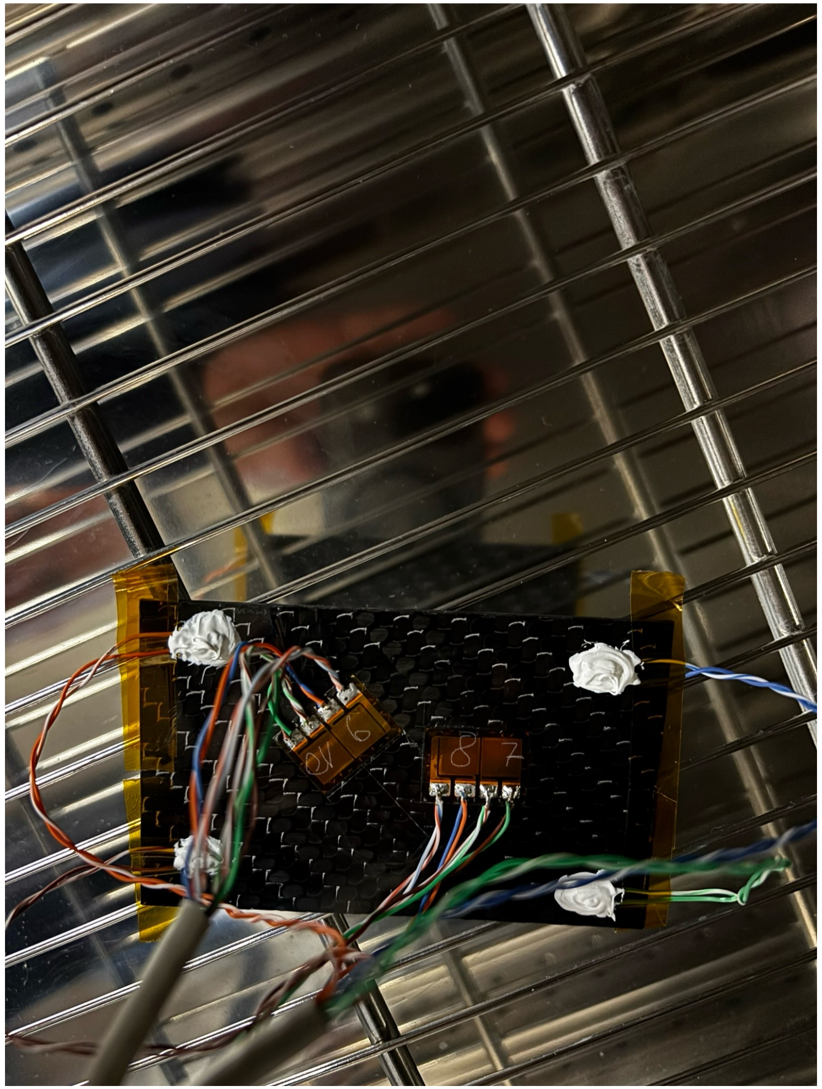


slope_measured ~ 12.3 e-6 / C

α_{Al} = slope_measured + α_{steel} ~ 24.5 e-6 / C

For both sensors decent agreement with expected CTE of Aluminium

Experimental setup with CF foil

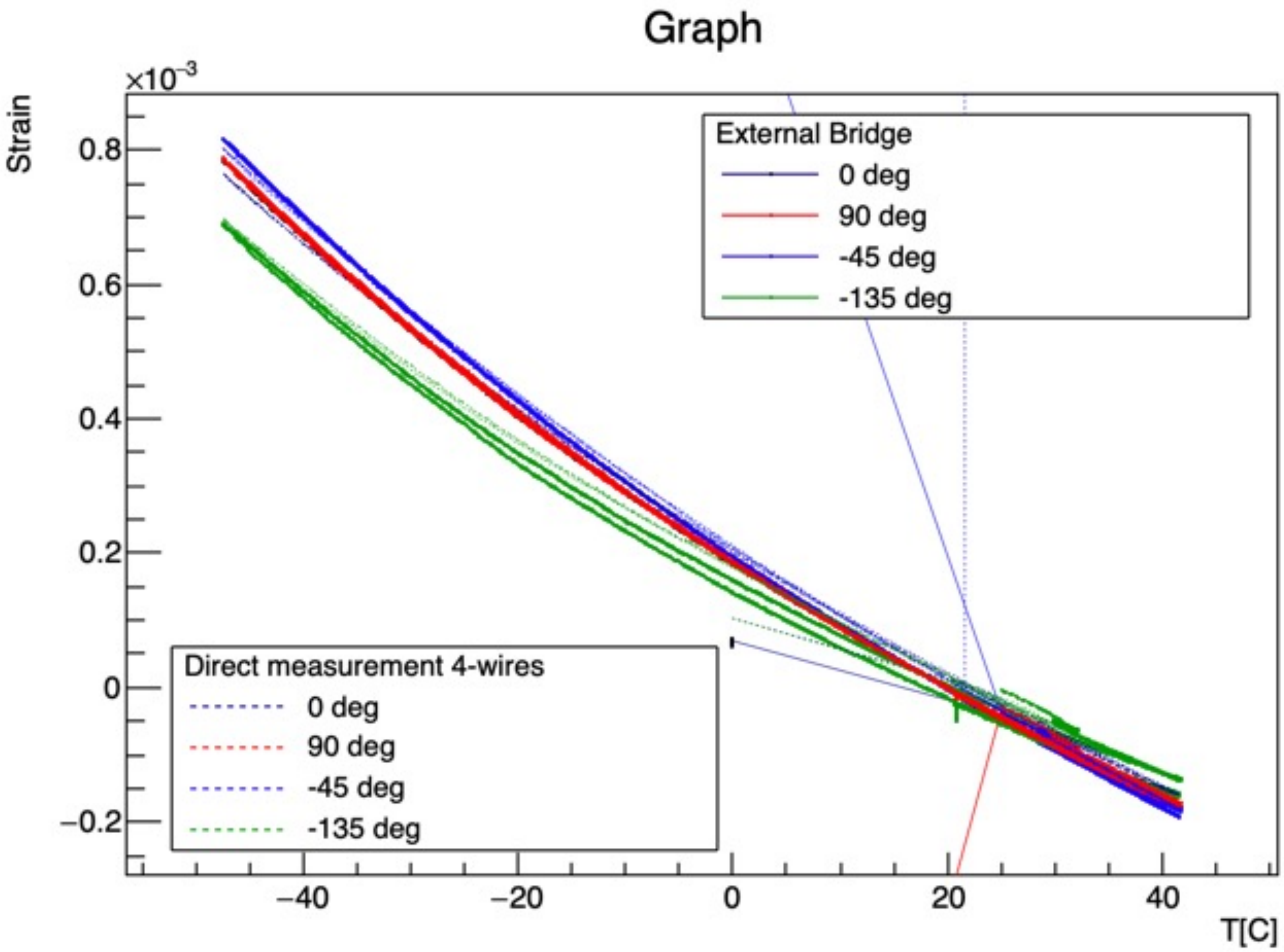


Properties for Carbon/Epoxy Composite Sheet

Property	Units	Value
Coefficient of thermal expansion - Longitudinal	$x10^{-6}$ K^{-1}	2.1
Coefficient of thermal expansion - Transverse	$x10^{-6}$ K^{-1}	2.1
Compressive Strength - Longitudinal	MPa	570
Compressive Strength – Transverse	MPa	570
Density	g cm^{-3}	1.6
Shear modulus - in-plane	GPa	5
Shear strength - in-plane	MPa	90
Ultimate Compressive Strain - Longitudinal	%	0.8
Ultimate Compressive Strain - Transverse	%	0.8
Ultimate Shear Strain - in-plane	%	1.8
Ultimate Tensile Strain - Longitudinal	%	0.85
Ultimate Tensile Strain - Transverse	%	0.85
Volume fraction of fibres	%	50
Young's Modulus - Longitudinal	GPa	70
Young's Modulus - Transverse	GPa	70

We perform a strain measurement in two ways:

- External wheatstone bridge + Voltage measurement from Keysight DAQM901A module Data Acquisition System
- Direct 4 wire measurement of strain (resistance) from Keysight DAQM901A module Data Acquisition System

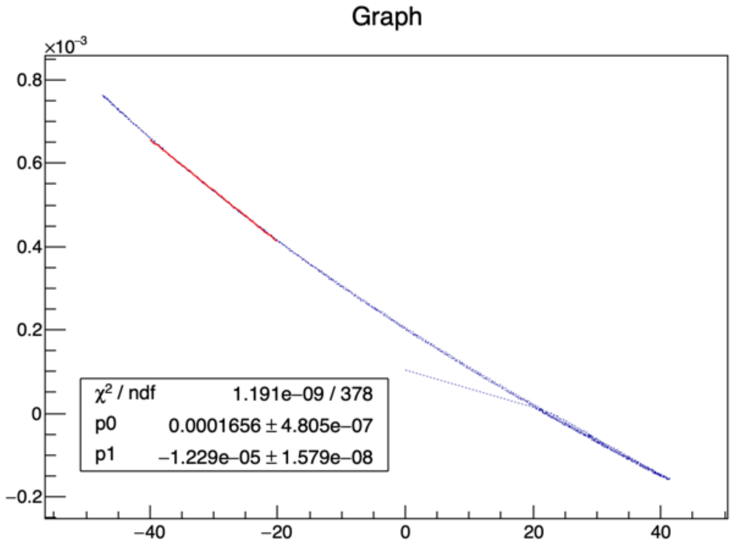


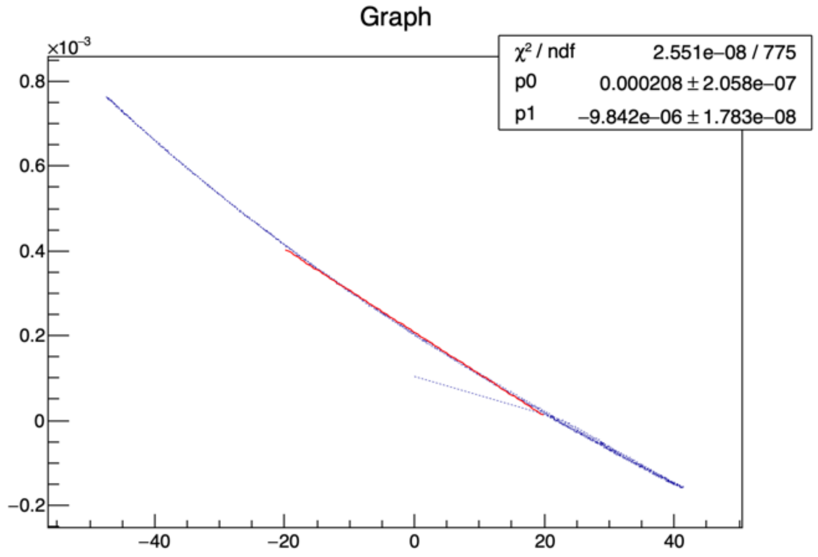
- in each direction, for the two types of measurement, we have same trend of strain vs T

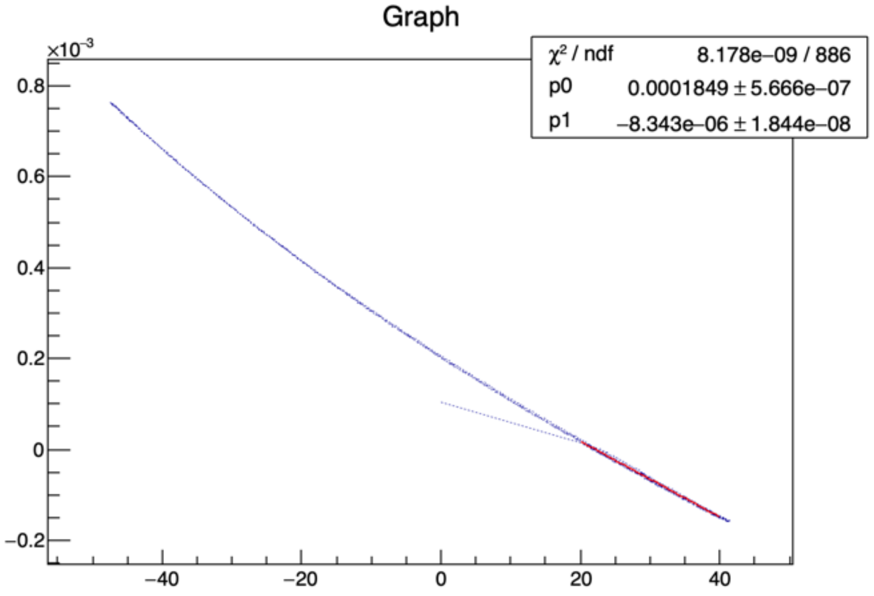
- for 0 and 90 degrees same trend of "strain vs T" and, therefore, same CTE, as expected from RS specs

- the trend of "strain vs T" of -45C and -135 C are a bit different. No specs available for these directions

Fit and CTE extraction



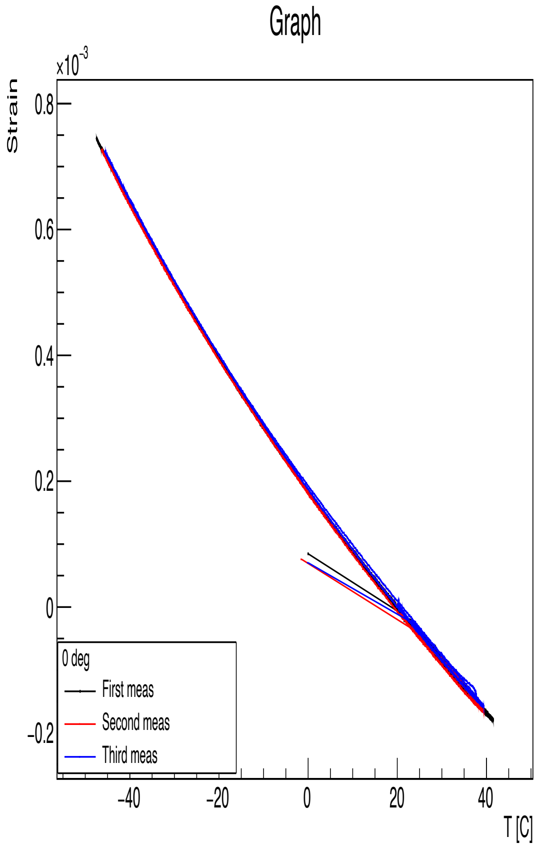


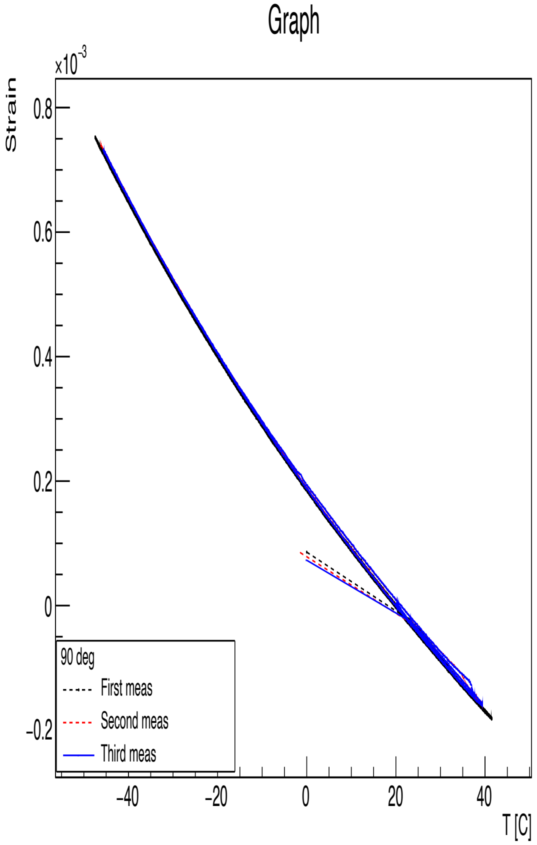


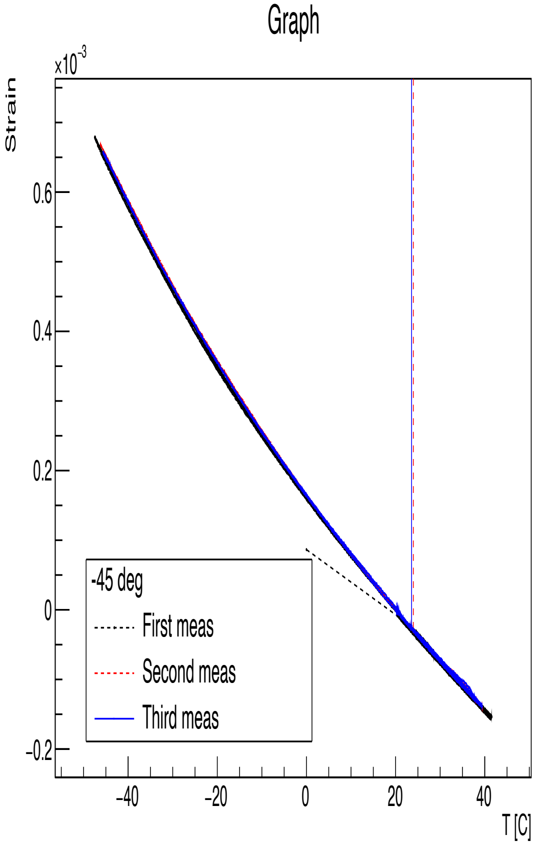
- The linear fit of in the [-20, + 20]C region for 0 deg gives CTE ~ (-9.8 + 12.1) ppm/C = 2.3 ppm/C, in decent agreement with RS specs of 2.1 ppm/C
- In the region [+20, +40]C the fitted CTE is ~(-8.3 + 12.1)ppm/C =3.8 pp/C
- In the region [- 40, - 20]C the fitted CTE is ~(-12.2 + 12.1) ppm/C ~ -0.1 ppm/C

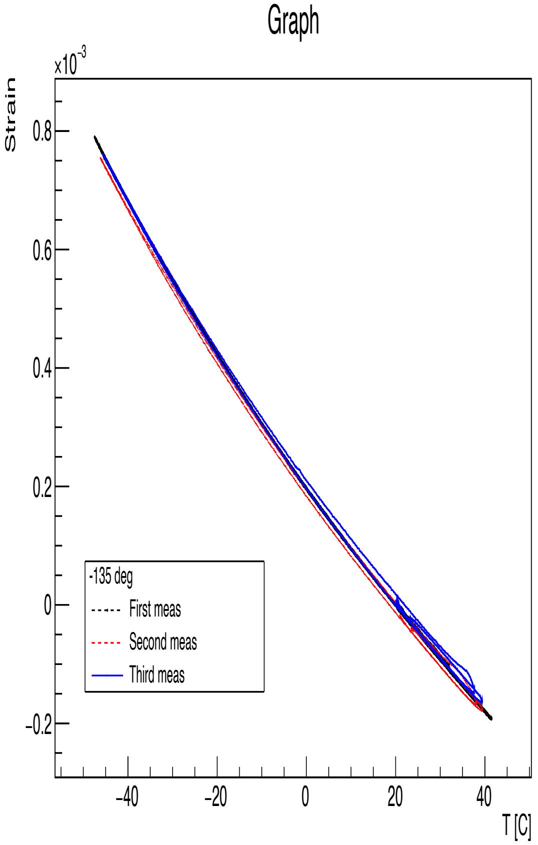
- 12.1 ppm/C is the CTE of steel 2018 used for thermal compensation

Reproducibility

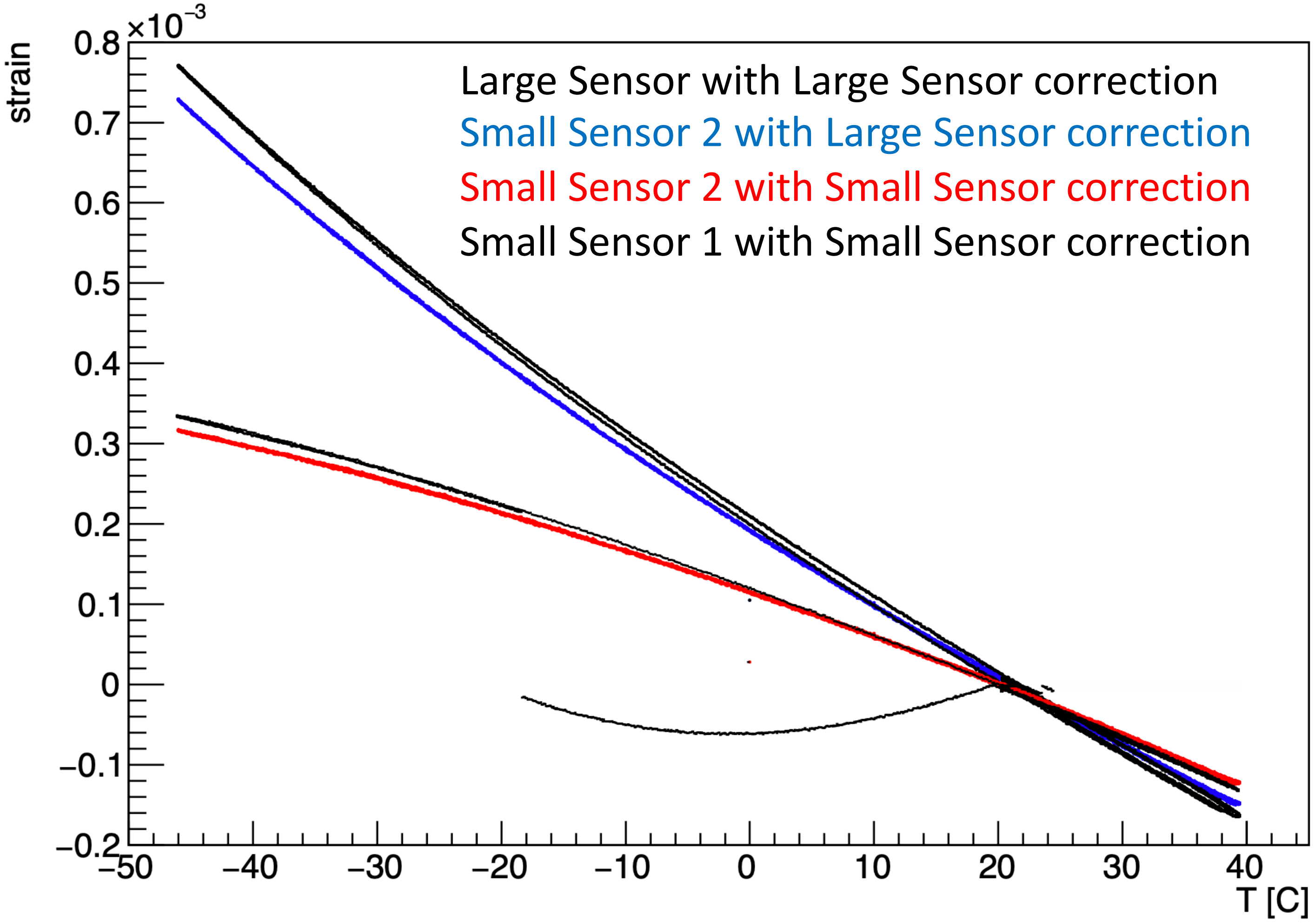


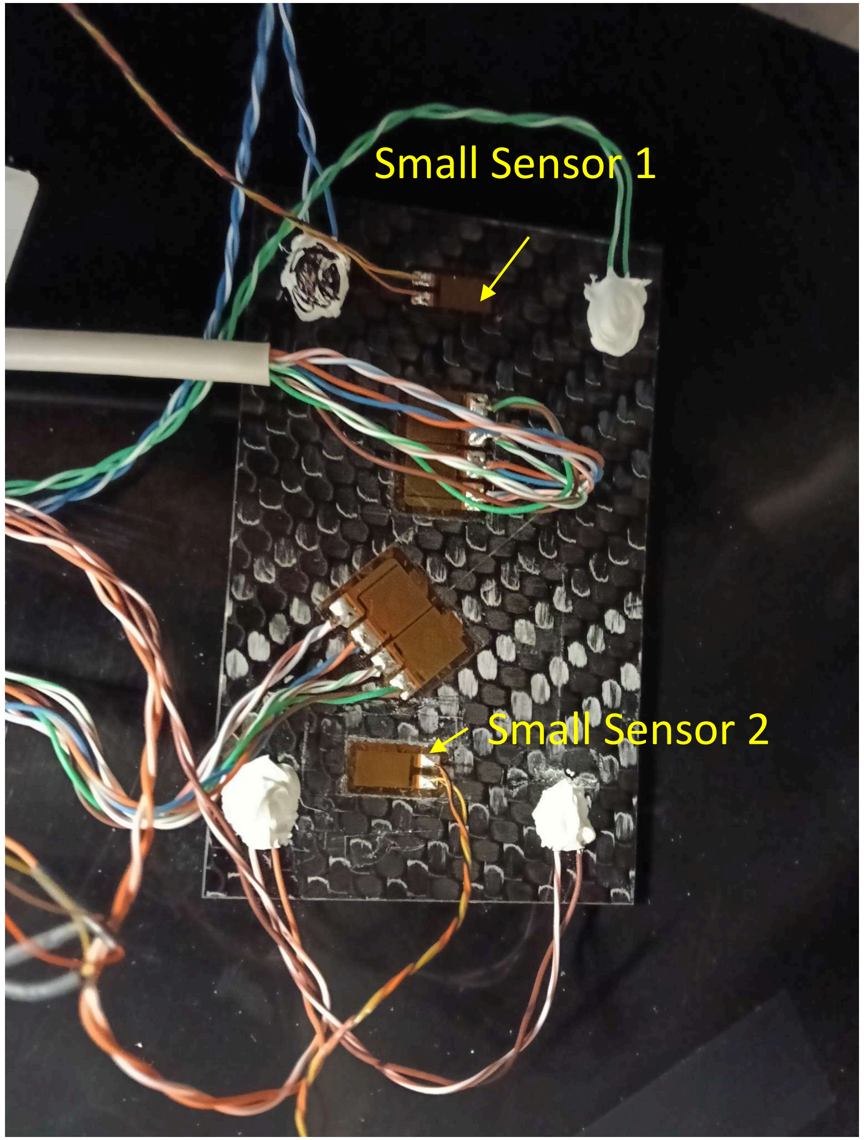






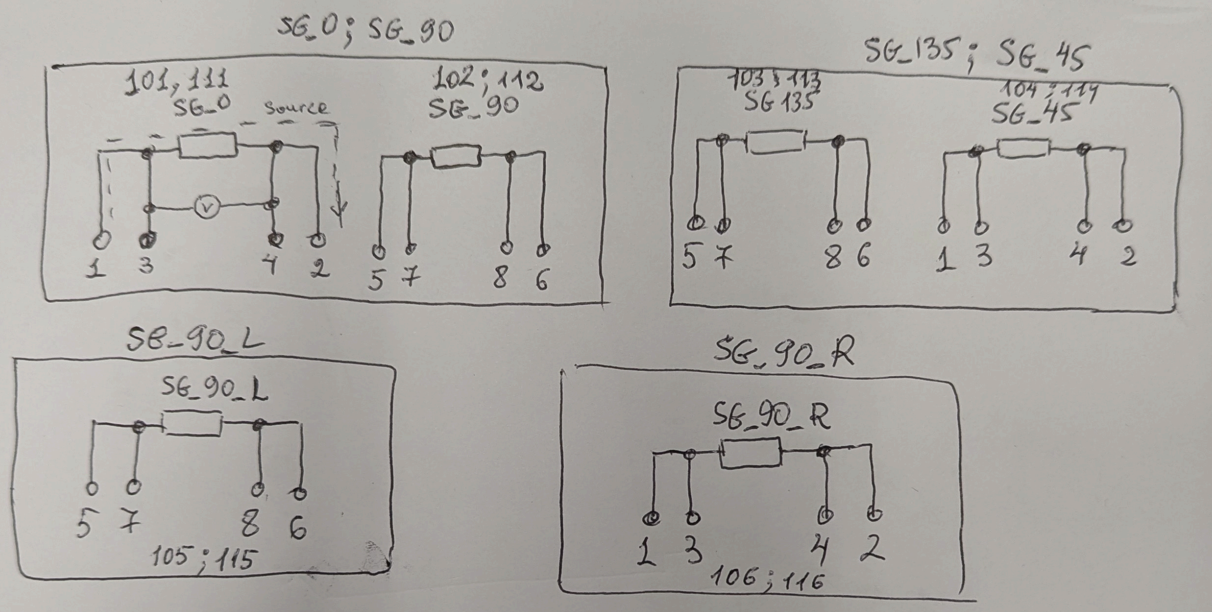
Small Mono-directional sensors





To be understood

Backup



NTCs 107, 108, (10K) calibrated
109, 110, (10K) no calibrated.