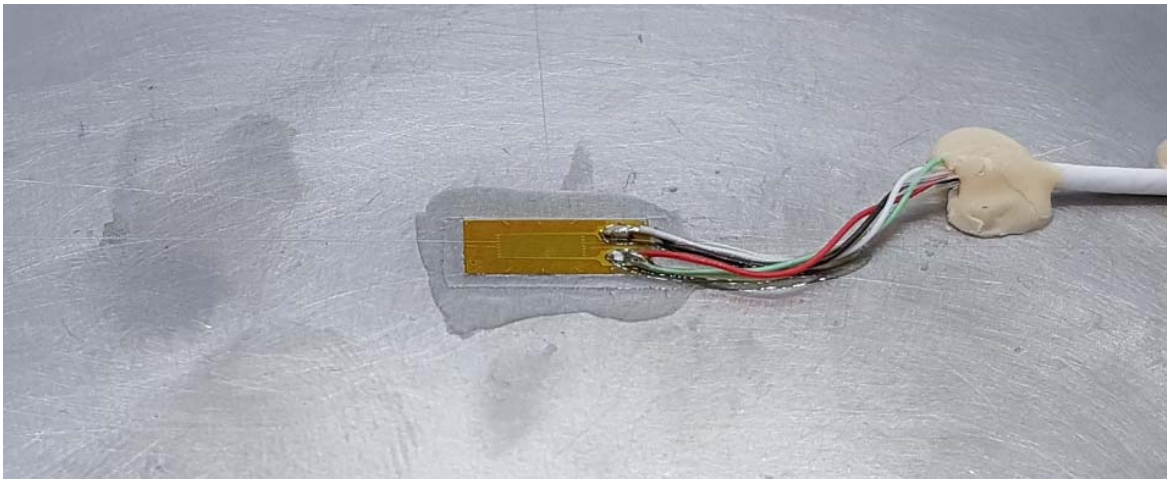
Temperature compensation of strain gauge ¼-bridges – Clear, brief and understandable

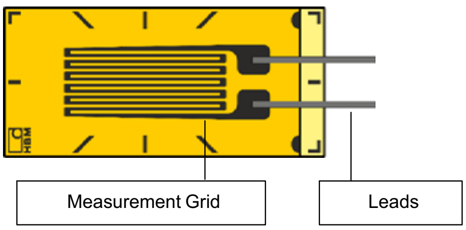


Abstract

This Technical Information gives a summary how an accurate correction of the strain values can be achieved by calculating it on an example. Different factors influence the strain signal on the amplifier:

- Material expansion differences of substrate/base material and strain gauge grid material interact with each other
- Resistance of the lead wires
- Temperature coefficient of the gauge factor
- Self-heating of the strain gauge
- Temperature dependency of the Youngs modulus
- Humidity

We will make an exemplary calculation to show you how thermal compensation in ¼ bridges can be established considering the most significant influences.



Exemplary calculation

- Strain measured (without any correction: 1000 µm/m)
- Temperature during test: 100 °C (constant)
- Gauge: 1-LY11-3/120 with 30 mm leads

Technical Information

HBM

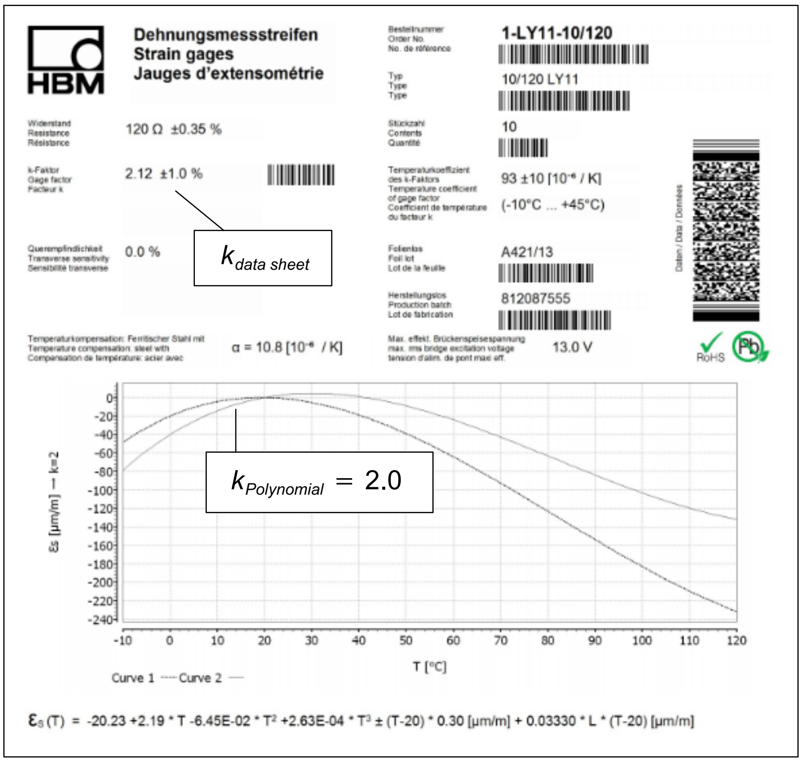
Correction of strain value with polynomial (but without correction of gauge factor varying by temperature)

The temperature response of a strain gauge depends on the interaction of the strain produced by different temperature expansion coefficient of the substrate/material and the CTE of the measurement grid material (they counteract), the temperature coefficient of the resistance of the measurement grid and the gauge factor of the strain gauge.

$$\varepsilon_T = \left(\frac{\alpha_R}{k} + \alpha_s - \alpha_M\right)\Delta T$$

ε_τ	Thermal strain caused by
α_R	Temperature coefficient of the gauge resistance [1/K]
α_S	Temperature coefficient of the substrate/structure [1/K]
α_M	Temperature coefficient of the strain gauge metal grid [1/K]
k	Gauge factor of te strain gauge

On each package the thermal output polynomial is given for a gauge factor k=2



Now let's calculate a specific test case:

$T = \textit{temperature during the test} = 100°C$ — Temperature during the test (The signal was set to zero at 20 °C)

$\varepsilon_u = \textit{uncorrected strain value} = 1000\,\mu m/m$ — Strain value shown on a strain measurement instrument without any correction

$$\varepsilon_t = \textit{thermal output polynomial strain gauge data sheet} = \underbrace{a_0 + a_1 \times T + a_2 \times T^2 + a_3 \times T^3 + \dots}_{\text{Polynomial from data sheet}} \pm \underbrace{\varepsilon_u}_{\text{Meas. uncertainty}} + \underbrace{\varepsilon_l}_{\text{Influence of leads}}\ *$$

Polynomial given on data sheet

$$\varepsilon_t = \underbrace{-20.23 + 2.19 \times T - 6.45 \times 10^{-2} \times T^2 + 2.63 \times 10^{-4} \times T^3}_{\text{Polynominal from data sheet}} \pm \underbrace{(T - 20) \times 0.3}_{\text{Meas. Uncertainty}} + \underbrace{0.033 \times (L) \times (T - 20)}_{\text{Influence of leads (our gauge has 30 mm leads attached)}}$$

$k_{Polynomial} = 2.0$

$k_{data\ sheet} = 2.12$

We subtract the strain initiated by thermal effects from the initial value and get a first rough correction of the strain value and correct the gauge factor. Additionally the gauge factor correction is performed (for many experimental tests this might be sufficient):

$$\varepsilon_c = \textit{strain value corrected with polynomial given on data sheet} + \textit{gauge factor correction} = \varepsilon_1 - \left(\varepsilon_2 \times \frac{k_{polynomial}}{k_{data\ sheet}}\right) \pm \textit{Meas.uncert.} - \textit{Influenceofleads}$$

$$\varepsilon_c = \underbrace{1000\frac{\mu m}{m}}_{\text{Uncorrected strain value}} - \Big(\underbrace{(-20.23 + 2.19 \times 100 - 6.45 \times 10^{-2} \times 100^2 + 2.63 \times 10^{-4} \times 100^3)}_{\text{Polynomial from data sheet}} \times \frac{2}{2.12}\Big) \pm \underbrace{(100 - 20) \times 0.3}_{\text{Measuring uncertainty}} - \underbrace{0.033 \times (30) \times (100 - 20)}_{\text{Influence of leads}}$$

$$\varepsilon_c = \underbrace{1000\frac{\mu m}{m}}_{\text{Uncorrected strain value}} \quad \underbrace{+184}_{\text{Polynomial + gauge factor corr.}}\frac{\mu m}{m} \quad \underbrace{\pm 24}_{\text{Meas. uncertainty}}\frac{\mu m}{m} \quad \underbrace{-79}_{\text{Influence of leads}}\frac{\mu m}{m}$$

$$\varepsilon_c = \underbrace{1105\frac{\mu m}{m}}_{\text{Corrected strain}} \pm \underbrace{24\frac{\mu m}{m}}_{\text{Meas. uncertainty}}$$

* The polynomial grade can vary on strain gauge type

** When measuring at constant temperature and the signal can be set to zero, the correction polynomial is zero

Gauge factor variation by temperature

In the previous section the strain correction by the polynomial and gauge factor adjustment was performed. For many experimental tests this is seen as sufficient.

The gauge factor (k-factor) varies additionally with temperature approximately linearly over a wide range. Therefore, a correction of the gauge factor can be considered in the uncorrected strain signal (not to be considered in the polynomial since in the polynomial the temperature dependency of the gauge factor is already included). It needs to be considered if the temperature coefficient is positive or negative. This depends on the grid materials (Constantan or CrNi (Modco).

On the HBM data sheet the temperature coefficient is given. The temperature adjusted gauge factor can then easily be calculated:

Temperaturkoeffizient des k-Faktors Temperature coefficient of gage factor	93 ±10 [10^{-6} / K]

k	Gauge factor printed on the data sheet
$\alpha_k = 93 \pm 10$	Temperature coefficient of the gauge factor [1/K]
$k_{T=k} + {}^{*}\alpha_k (T - T_{Ref})$	Correction formula of the gauge factor
$k_T = 2.12 + \times \frac{93}{K} \times \frac{1}{1000000}(100 - 20)\, k = 2.127$	Corrected gauge factor considering the temperature influence

The ultimate formula considering the thermal output and the gauge factor variation by temperature both is noted as followed:

$$\varepsilon_k = 1000\frac{\mu m}{m} \times \frac{k_{data\ sheet}}{k_T} + \left(Polynominal\ on\ data\ sheet \times \frac{k_{polynomial}}{k_{data\ sheet}} \right) \pm Meas.\ uncert. + Influence\ of\ leads$$

$$\varepsilon_k = \underbrace{1000\frac{\mu m}{m}}_{\text{Uncorrected strain}} \times \underbrace{\frac{k_{data\ sheet}}{k_T}}_{\text{Gauge factor corr.}} + \underbrace{184\frac{\mu m}{m}}_{\text{Polynomial from data sheet}} \quad \underbrace{\pm 24\frac{\mu m}{m}}_{\text{Measuring uncertainty}} \quad \underbrace{-79\frac{\mu m}{m}}_{\text{Influence of leads}}$$

$$\varepsilon_k = \underbrace{1000\frac{\mu m}{m} \times \frac{2.12}{2.127}}_{\text{Uncorrected strain}} + \underbrace{184\frac{\mu m}{m}}_{\text{Polynomial + gauge factor corr.}} \quad \underbrace{\pm 24\frac{\mu m}{m}}_{\text{Measuring uncertainty}} \quad \underbrace{-79\frac{\mu m}{m}}_{\text{Influence of leads}}$$

Strain value considering the correction with polynomial + gauge factor variation by temperature:

$$\varepsilon_k = 996\frac{\mu m}{m} + 184\frac{\mu m}{m} + 24\frac{\mu m}{m} - 79\frac{\mu m}{m} = 1101\frac{\mu m}{m} \pm 24\frac{\mu m}{m}$$

Additional consideration of deviating temperature coefficient of substrate material from strain gauge grid material

In the optimized test case the temperature coefficient of the strain gauge perfectly suits to the material. In reality there might be slight deviations. An approximate fit to correct the measured strain value is given by the following formula. In this case we assume that a strain gauge adapted to ferritic steel (10.8 ppm/K) was used on an aluminum material (23ppm/K):

$$\varepsilon_f = \varepsilon_{t\,(Steel)} - (\alpha_{23} - \alpha_{10.8}) \times \Delta T$$

$$\Delta T = T - T_{ref}$$

$$\varepsilon_f = 1101\frac{\mu m}{m} - (23 - 10.8) \times (100 - 20) - 79\frac{\mu m}{m} \pm 24\frac{\mu m}{m} = 125\frac{\mu m}{m} \pm 24\frac{\mu m}{m}$$

So for our specific case assuming that we have bonded a different strain gauge compensated to aluminum

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