Welcome to the webinar on "Temperature compensation of strain gauges"

The presentation starts at 15.00 CET

stress analysis
... the experience counts

Organizational information

- All participants' **microphones** are **muted** during the webinar.
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- Please use the '**Questions and answers**' window, if you have any questions. We will answer questions at the end of the presentation.

- We will email the presentation to you after the webinar.
- The webinar is recorded and will soon be made available on our website.

Presenter

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Agenda

❶ **The influence of temperature**

- Overview of temperature-dependent influence quantities
- Description of the individual influence quantities

❷ **Compensation**

- Temperature-compensated strain gauge (SG)
- Compensation through calculation
- Wheatstone bridge (half- and full-bridge circuit)
- Multiple-wire technology
- Carrier-frequency technology

❸ **Strain gauges for higher temperature ranges**

- Strain gauge series
- Adhesives

❹ **Conclusions, additional information and Q&A**

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Temperature-dependent influences on strain gauge measurements
(measurements in experimental stress analysis)

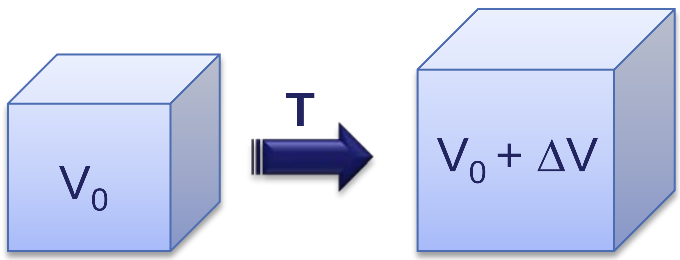
- Material strain (apparent strain)
- Cable resistance
- Temperature coefficient of the gauge factor
- Temperature dependence of the modulus of elasticity
- Self-heating of the strain gauge (excitation voltage)
- Climate/relative humidity
- Creep of the adhesive *(exceeding of temperature limits)*

Material strain

Material expands as a result of increasing temperature.

This is described by the material's expansion coefficient α (alpha)
(material dependent - e.g. steel ~11 ppm/K [11 µm/m / °C])

→ Measurement of <u>apparent strain</u> (strain without load)



Change in volume

$$\Delta V = \alpha \cdot V_0 \cdot \Delta T$$

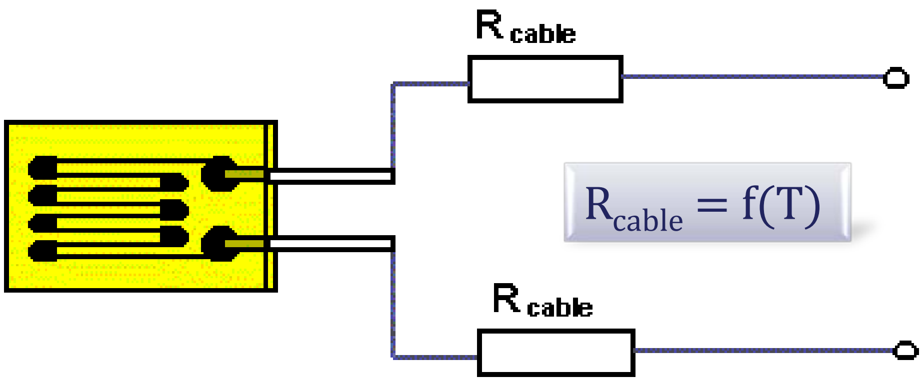
→ Use of temperature-compensated SG and/or adequate SG circuits
(see section 2)

Cable influence

The cable resistance is added to the SG resistance and thus influences the measurement*.

Apart from the resulting zero drift and reduction of the effective gauge factor, the cable resistance is temperature dependent.

→ Measured value depends on cable temperature



$R_{cable} = f(T)$

→ Use multiple-wire technology
(see section 2)

**When 2-wire circuit is being used*

Temperature dependence of the gauge factor

The gauge factor is a key strain gauge property. It describes the relationship between the strain and the relative change of resistance.

The gauge factor is temperature dependent
→ Temperature coefficient of the gauge factor

$$\varepsilon = \frac{\Delta l}{l_0}$$

$$\frac{\Delta R}{R_0} = k \cdot \varepsilon$$

Typical value: 0.01%/K (i.e. $1 \cdot 10^{-4}$/K)

→ Is relatively small - usually ignored.
Could be compensated through calculation (when measuring temperature)

Temperature dependence of the modulus of elasticity

Modulus of elasticity is a material-dependent property of the measuring body.

It is the ratio of measured strain to mechanical stress.

The modulus of elasticity is temperature dependent.

$$\sigma = \varepsilon \cdot E \quad \left(with\ E = f_{(T)} \right)$$

Typical value for steel $T_K \approx -2\%/K$ (i.e. $-2 \cdot 10^{-4}/K$)

➔ Is typically ignored in experimental stress analysis.

With high-precision transducers (that can be calibrated), compensation through temperature-dependent nickel elements in the bridge.

Self-heating of the strain gauge

The excitation voltage causes self-heating of the strain gauge compared to the measuring body.

Dissipation of the thermal output to the measuring body depends on its thermal conductivity (λ).

With measuring bodies that are poor conductors, there may be a temperature difference between the measuring body and the strain gauge.

This disrupts the functioning of a temperature-compensated SG.

$$U_{max} = \sqrt{R \cdot A \cdot \lambda \cdot \frac{\Delta T}{d}}$$

➔ Observe maximum excitation voltage

Temperature-dependent influence quantities: Climate & adhesive

Climate/relative humidity

Insufficient measuring point protection may result in a zero drift depending on the relative humidity.

This is due to the fact that the adhesive and the SG carrier material attract and hold water molecules (hygroscopy).

➔ Thoroughly cover the measuring point

Creep of the adhesive

Adhesives soften as a result of increasing temperature and can no longer transfer the strain in full.

Comparable to a decreasing gauge factor

➔ Observe the temperature limits of the adhesives used

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Temperature-compensated SG

The temperature response of strain gauges is matched such that they compensate for the apparent strain (measuring body expansion resulting from temperature).

→ SG (temperature response matching) in line with the measuring body material

Code	Material (examples)	α ($\cdot 10^{-6}$ / °K)
1	Ferritic steel	10.8
3	Aluminum	23
5	Austenitic steel	16
6	Quartz glass/composite	0.5
7	Titanium/gray cast iron	9.0
8	Plastic	65
9	Molybdenum	5.4

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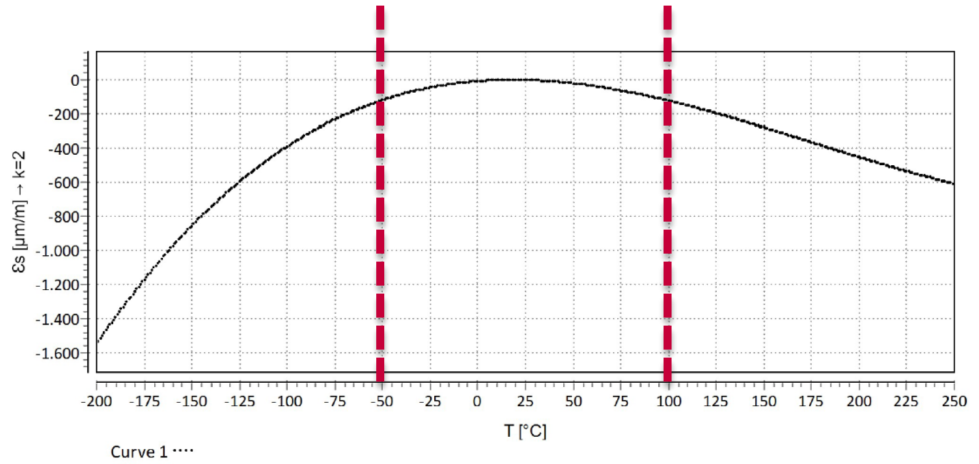
Limitations of the temperature-compensated strain gauge (SG)

The better part of the apparent strain is compensated for by selecting the right SG for each material; however, a residual error remains (non-linear proportion).

→ *This error is determined during production and is specified in the data sheet (representation as polynomial and in a graph).*

Optimization for typical temperature range



$\varepsilon_S(T) = -7.45 + 0.86 * T - 2.48E{-}02 * T^2 + 4.71E{-}05 * T^3 \pm (T-20) * 0.60$ [µm/m]

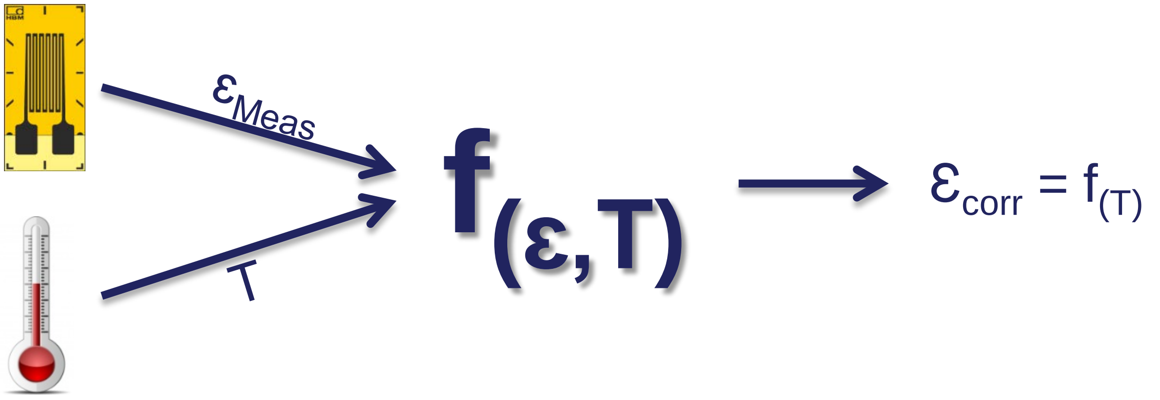
→ In the event of large temperature variations during measurement, the temperature can be measured in parallel and the residual error compensated for by calculation
(DAQ software, e.g. catman® provides the corresponding functions)

Compensation through calculation

Apart from the residual error, other errors of a strain gauge without/with insufficient temperature response matching or other minor errors can be compensated for through calculation *(e.g. temperature dependence of the gauge factor)*.

For this purpose, the temperature is measured in parallel and the measured strain corrected by online or post-process calculation of a channel.

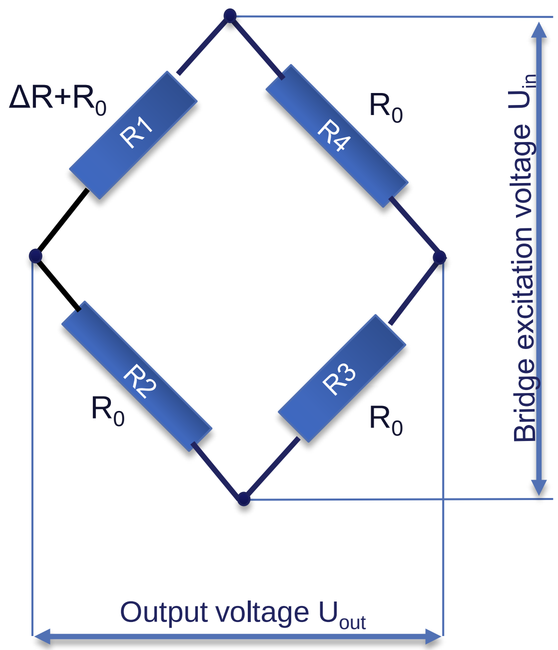
Temperature gradients need to be taken into account *(if necessary, several measurement points need to be allowed for temperature)*



Principle of the Wheatstone bridge, in general

The Wheatstone bridge converts minimal changes in resistance into a voltage that can be measured.

The 4 resistors can be replaced with one, two or four SG *(quarter, half or full bridge)*



$$\frac{U_{out}}{U_{in}} = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right)$$

$$\varepsilon = \frac{\Delta l}{l_0}$$

$$\rightarrow \Delta R \sim \Delta l \sim \varepsilon$$

$$\frac{\Delta R}{R_0} = k \cdot \varepsilon$$

$$\frac{U_{out}}{U_{in}} = \frac{k}{4} \cdot (\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)$$

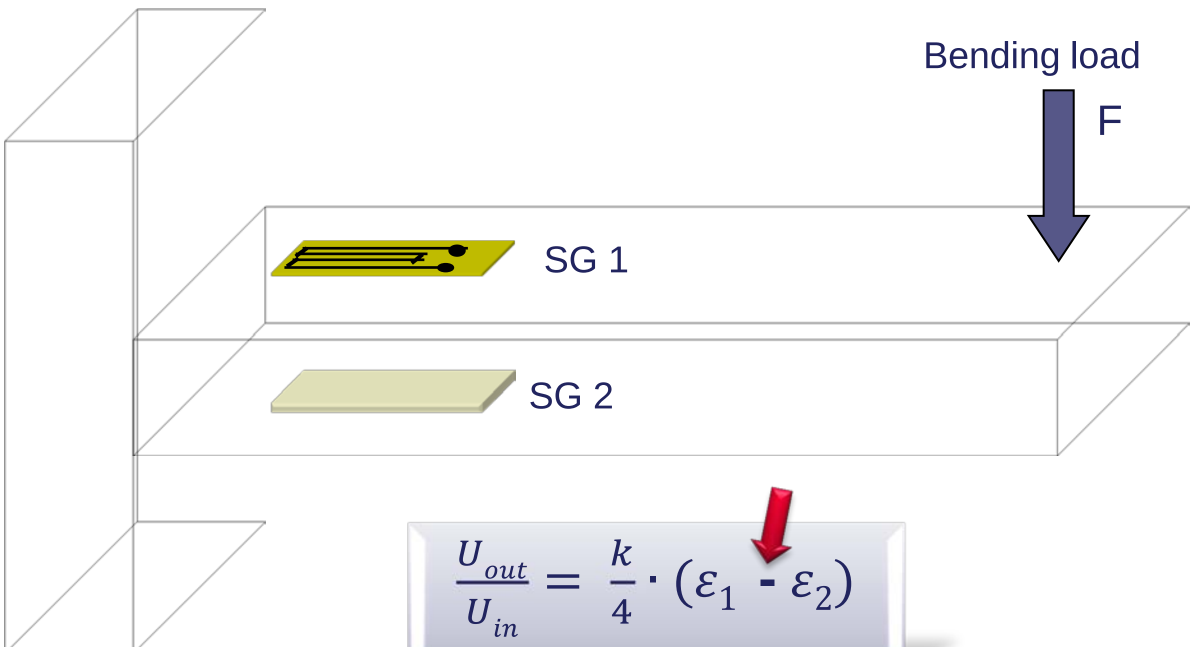
➔ **The different signs of the individual bridge arms are incorporated into result** *(i.e. possibility of compensation)*

Temperature compensation (example of a bending beam)

When a load is applied to a bending beam, elongation (+) occurs on one side and shortening (-) on the other side.

Correctly wired in a Wheatstone bridge circuit, you get the dual signal.

Strain resulting from an increase in temperature has the same sign for both strain gauges. They eliminate one another in the Wheatstone bridge.



$$\frac{U_{out}}{U_{in}} = \frac{k}{4} \cdot (\varepsilon_1 - \varepsilon_2)$$

Strain (bending load):

SG 1: +
SG 2: -

➔ **Doubling**

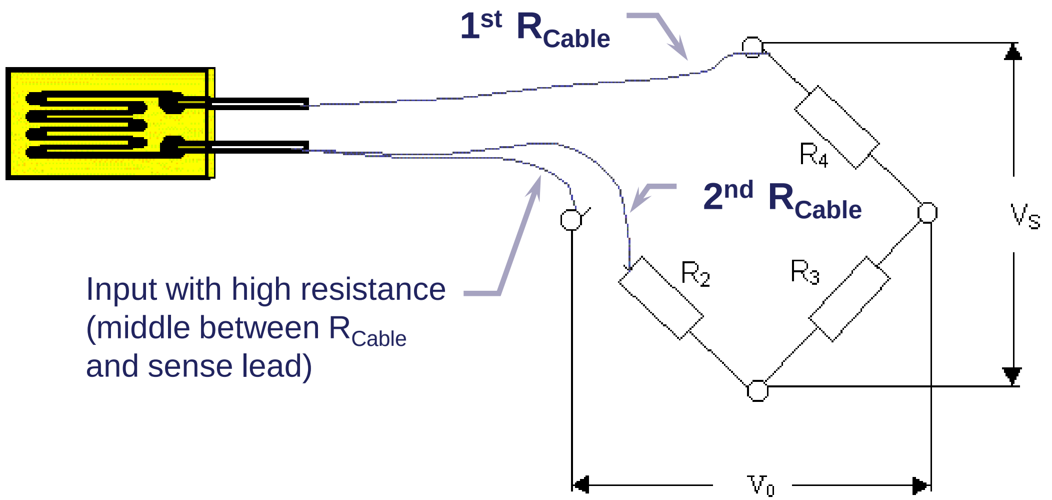
Elongation due to increased temperature:

SG 1: +
SG 2: +

➔ **Elimination**

Multiple-wire technology

The effect of the cable resistance can be largely compensated for through the use of a three wire circuit, provided that the supply leads are connected to different arms of the Wheatstone bridge by an additional third lead.



➔ Apart from the influence of unbalanced cables and temperature gradients, the effects are compensated for through the use of the three wire circuit.

Furthermore, the four wire circuit(*) can be used, which compensates for all cable influences.

** Circuit patented by HBM*

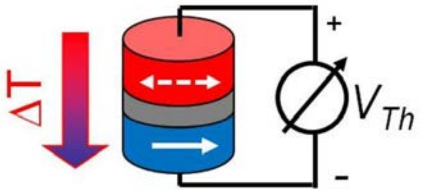
Temperature compensation: Carrier-frequency amplifier

Thermoelectric voltages

The thermoelectric effect causes a temperature-dependent voltage where different materials are joined.

This effect is used in thermocouples.

Effects on SG measurement system (SG + amplifier) *(temperature-dependent zero error)*

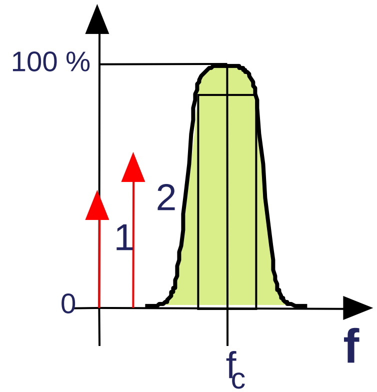


Carrier-frequency amplifier

Thermoelectric voltages can be largely compensated for through the use of a carrier-frequency amplifier.

Here, in most cases, the excitation voltage is sinusoidal and, as a result, the measurement signal is modulated onto a periodic signal.

It is digitally demodulated after a low-pass filter such that the quasi-static thermoelectric voltages are compensated for on the path to the measuring amplifier.



1: Thermoelectric voltages
2: 50 Hz hum

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Strain gauges for higher temperature ranges: Strain gauge series

Temperature limits of foil strain gauges

The temperature range of foil strain gauges is limited depending on the materials used.

The maximum is about 300°C to 400°C.

In addition, strain gauges for high temperatures based on other principles are available.

Temperature limits of HBM SG series:

Y series	200°C
M series	300°C
C series	250°C
G series	200°C
Pre-wired SG	150°C
V series	105°C

Temperature limits of adhesives

When an adhesive softens as a result of an increase in temperature, strain is no longer transmitted in full. An adhesive for SG must be very brittle.

For this reason, it is essential to observe the temperature limits of adhesives.

Temperature limits of adhesives from HBM:

A distinction is made between cold-curing and hot-curing adhesives depending on whether the adhesive cures at ambient temperature or whether an oven is required.

Hot-curing:

- EP310S 310°C
- EP150 150°C

Cold-curing:

- Z70 120°C
- X60 80°C
- X280 280°C

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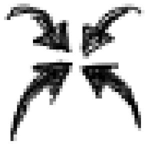
Conclusions



Conclusions

- Different temperature-dependent influence quantities affect measurements using electrical strain gauges

- When variations in temperature have to be expected during the measurement, the following two influence quantities should be compensated for at least:
  - Apparent strain (material strain)
  - Cable resistance (absolute [zero point] & temperature dependence)

- Other influence quantities are ignored or compensated for through calculation

- Suitable compensation measures:
  - Temperature-compensated SG
  - Half or full bridge circuit
  - 3- or 4-wire circuit

- Choose suitable SG series and adhesives for higher temperature ranges.

Additional information

www.hbm.com/strain

Strain Gauges & Accessories for Strain Measurement

Our range of strain gauges comprises of an **extensive assortment** for the most widely differing strain measurement applications – from **experimental stress analysis**, **durability testing** through **transducer manufacturing**.

We have **optical strain gauges** too! Optical sensors based on **Fiber Bragg technology (FBG)** are a reliable and safe solution for high-precision measurements even under difficult and harsh environments. For more information on our optical strain gauges, click here.

If you can't find the right strain gauge for your unique application, we will work with your design team to **customize a strain gauge that will meet your specifications**. Our custom sensor team will design and develop your strain gauge and sensor from the design phase all the way to the finished product. For more information on our custom sensors, click here.

Additionally, HBM offers all the necessary **accessories and components** for the **installation of your strain gauge**.

Find the equivalent strain gauge

Enter strain gauge part numbers from other manufacturers and immediately find the HBM equivalent.

Strain gauge catalog

Download the strain gauge catalog (PDF)

HBM's reference book

Download our reference book: **An Introduction to Measurements using Strain Gauges**.

Strain Gauges & Accessories Overview

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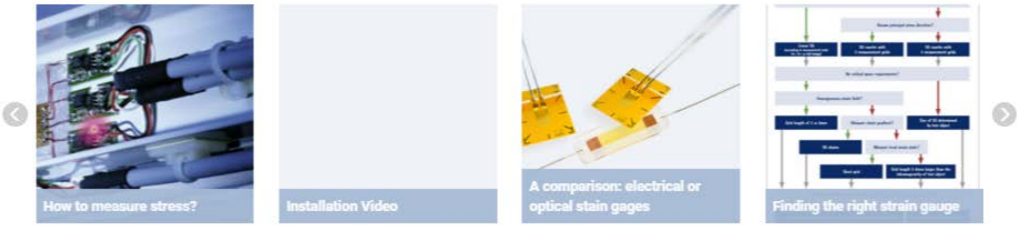
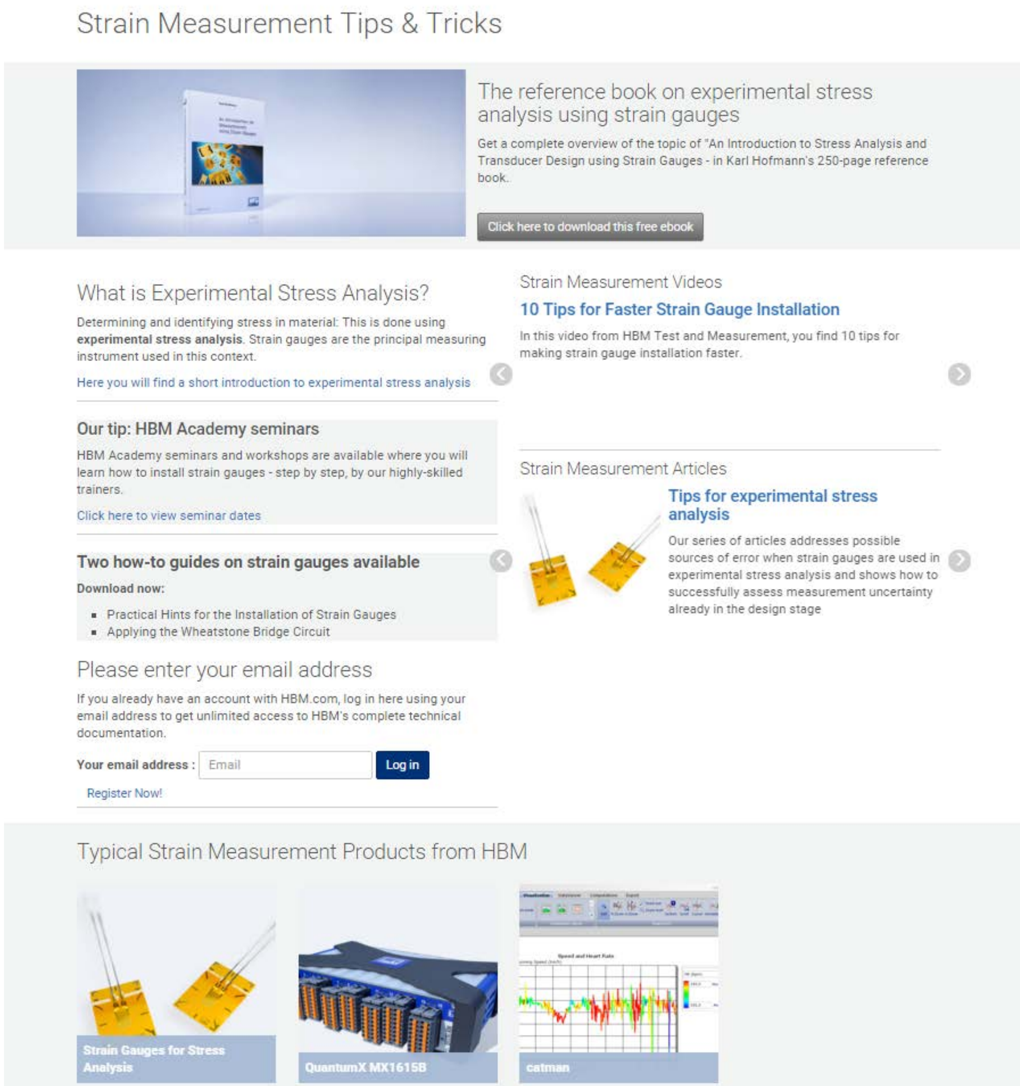


Additional information

www.hbm.com/en/3179/tips-and-tricks-experimental-stress-analysis/



Strain Measurement Tips & Tricks

The reference book on experimental stress analysis using strain gauges

Get a complete overview of the topic of "An Introduction to Stress Analysis and Transducer Design using Strain Gauges - in Karl Hofmann's 250-page reference book.

Click here to download this free ebook

What is Experimental Stress Analysis?

Determining and identifying stress in material: This is done using **experimental stress analysis**. Strain gauges are the principal measuring instrument used in this context.

Here you will find a short introduction to experimental stress analysis

Our tip: HBM Academy seminars

HBM Academy seminars and workshops are available where you will learn how to install strain gauges - step by step, by our highly-skilled trainers.

Click here to view seminar dates

Two how-to guides on strain gauges available

Download now:

- Practical Hints for the Installation of Strain Gauges
- Applying the Wheatstone Bridge Circuit

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- Residual stress measurements by hole drilling in accordance with ASTM E8372013

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- Dynamic Testing and Analysis of Inverters, Electric Motors and Generators Beyond the Typical Power Analyzer

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