Welcome to the webinar: “An Introduction to Measurements using Strain Gauges”
Dirk Eberlein

- Product and Application Manager
- Diploma in Engineering
- 20 years of experience in test and measurement
- Product Manager for electrical strain gauges
- E-Mail: dirk.eberlein@hbm.com
Agenda

1. Historical Overview
2. Basic physical principles
3. Structure and working principle
4. Advantages and disadvantages
5. Applications
Historical overview

1843: C. Wheatstone describes effect of change of resistance in electrical conductor due to effects of mechanical stress

1938: E.E. Simmons und A.C. Ruge (USA) invent almost simultaneously but independently the strain gauge

1941: company Baldwin-Southwark Corp., US for production of strain gauges founded

1952: first metal foil strain gauge produced

1963: start production of metal foil strain gauges at HBM, Darmstadt
Dear Professor Ruge:

The Patent Committee has considered your communication of February 20, 1939, relating to Resistance Strain Gages, Wire Type.

It appears that this work probably involves invention and that it comes within the category of our patent policy which applies to inventions arising from the programs of research in Institute laboratories.

It is the general policy of the Committee, however, to pay attention primarily to matters which may prove to be of major importance and, while this development is interesting, the Committee does not feel that the commercial use is likely to be of major importance.

Accordingly, the Committee has voted that any rights which the Institute may have in this invention should be waived in your favor. This leaves you free to treat the invention entirely as a personal matter.

Sincerely yours,
Basic physical principles of strain gauges

- Mechanical strain gauge
- Capacitive strain gauge
- Piezoelectric strain gauge
- Vapor-deposited (thin-film) strain gages
- Fiber-Bragg Sensors
- Semiconductor strain gauge
- Metal foil strain gauge
### Basic physical principles of strain gauges

<table>
<thead>
<tr>
<th>Semiconductor strain gauge</th>
<th>Metal foil strain gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td>High output signal (k ca. 180)</td>
<td>Lower output signal (k ca. 2)</td>
</tr>
<tr>
<td>Low linearity</td>
<td>High linearity</td>
</tr>
<tr>
<td>High temperature error</td>
<td>Known and reproducible temperature characteristics</td>
</tr>
<tr>
<td>Handling not that easy</td>
<td>Easy application</td>
</tr>
<tr>
<td>Low variance of patterns</td>
<td>Large type variety</td>
</tr>
</tbody>
</table>
Structure of metal foil strain gauges

- Cover
- Carrier
- Measuring grid
- Leads
- Active length
Physical principal (electrical + mechanical)

Example: wire with positive or negative strain

\[ R = \rho \cdot \frac{l}{A} \]

\[ \frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + \frac{\Delta l}{l} - \frac{\Delta A}{A} \]

change of specific resistance due to volume change

geometric part

\[ \frac{\Delta R}{R_0} = k \cdot \varepsilon \]
Which changes in resistance appear?

\[
\frac{\Delta R}{R_0} = k \cdot \varepsilon
\]

- \( k \): ca. 2
- \( R_0 \): resistance strain gauge (e.g. 120 \( \Omega \))
- \( \varepsilon \): strain to be measured
  - e.g. 1,000 \( \mu \text{m/m} \) ("nominal strain" in transducer manufacturing)
- Example:
  \( \Delta R = 0.24 \ \Omega \)
  with \( \varepsilon = 1,000 \ \mu \text{m/m} \) and \( R_0 = 120 \ \Omega \)
Wheatstone bridge circuit

\[ V_A \]

\[ V_B \]
Advantages of metal foil strain gauges

- Applicable on (nearly) all materials
- Low mass / small dimensions
- Wide frequency range
- Easy to handle
- Lossless, strong connection strain gauge - surface
- High linearity over a large strain range
- **Predictable and reproducible temperature effects**
- High temporal stability
- Low costs
- Large type variety
  - Customer-specific strain gauges
Disadvantages of metal foil strain gauges

- Low relative change in resistance
  - Wheatstone bridge circuit inevitable

- Limited temperature ranges
  - Particularly in transducer manufacturing

- Not reusable

- Sensitivity against:
  - Humidity
  - Temperature (temperature gradients!)
  - Ionizing radiation
  - Magnetic fields
# Fields of application strain gauge

<table>
<thead>
<tr>
<th>Experimental tests</th>
<th>Transducer manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Experimental stress analysis</td>
<td>- Force</td>
</tr>
<tr>
<td>- Residual stress analysis</td>
<td>- Mass</td>
</tr>
<tr>
<td>- Analysis of loading</td>
<td>- Torque</td>
</tr>
<tr>
<td>- Life-time analysis</td>
<td>- Pressure</td>
</tr>
<tr>
<td>- Determining thermal stress</td>
<td>- Strain</td>
</tr>
</tbody>
</table>

- Experimental tests:
  - Experimental stress analysis
  - Residual stress analysis
  - Analysis of loading
    - Life-time analysis
  - Determining thermal stress

- Transducer manufacturing:
  - Force
  - Mass
  - Torque
  - Pressure
  - Strain
Aim of experimental analysis

- Basis for stress calculation of structural elements
- Proof of validity of mathematical design models (FEM)
- Basis for component optimization
  - Durability
  - Material utilization
  - Structural health analysis
  - Stress analysis
- Determination of residual stress
- Determination of thermal stress
Field of application: experimental stress analysis

- **Aim:**
  - Determination of mechanical principal normal stress $\sigma_1$ and $\sigma_2$ in absolute value and direction

- **Procedure:**
  - Strain measurement on component surface with strain gauge
  - Calculation of mechanical stress with measured strains
Mechanical stress

- **Cause**
  - Load-induced stress (exterior mechanical load)
  - Residual stress (interior forces)
  - Thermal stress (restraint of free thermal expansion)

- **Type**
  - Normal stress
  - Shear stress

- **State**
  - uniaxial
  - biaxial
  - triaxle

- For strength consideration mechanical stresses are relevant independently of their cause
Biaxial stress state with unknown principal directions

- Which mechanical stresses appear and in which direction do they proceed?
Biaxial stress state with unknown principal directions

- Usage of 3 measuring grid rosettes
- Strain measurement in 3 directions (measuring grid a, b and c)

0°/45°/90°-rosette (RY3)

0°/60°/120°-rosette (RY7)
Biaxial stress state with unknown principal directions

- Step 1: Application strain gauge rosette on component
  - Alignment of strain gauge rosette on component arbitrary
Biaxial stress state with unknown principal directions

- Step 2: Connection strain gauge rosette to suitable measurement system
  - 3 separate quarter bridges per strain gauge rosette

Example: QuantumX MX1615B
Biaxial stress state with unknown principal directions

- Step 3: Determination of principal stress $\sigma_1$ and $\sigma_2$ out of measured strains $\varepsilon_a$, $\varepsilon_b$ and $\varepsilon_c$

$$\sigma_{1/2} = \frac{E}{1-\nu} \cdot \frac{\varepsilon_a + \varepsilon_c}{2} \pm \frac{E}{\sqrt{2(1+\nu)}} \cdot \sqrt{\left(\varepsilon_a - \varepsilon_b\right)^2 + \left(\varepsilon_c - \varepsilon_b\right)^2}$$

*Only valid for 0º/45º/90º rosettes!*
Biaxial stress state with unknown principal directions

- Step 4: Determination of direction of principal stress $\sigma_1$ and $\sigma_2$
  - Angle $\varphi$ defines the direction of first principal stress $\sigma_1$ and is measured counterclockwise starting at measuring grid $a$
  - Second principal stress $\sigma_2$ is defined through $\varphi + 90^\circ$. 
Biaxial stress state with unknown principal directions

- Hint for application:
  - Alignment of rosette or **measuring grid** a parallel or perpendicular to distinctive objects (edge, margin, …)
Biaxial stress state with unknown principal directions

- Calculation of absolute value and direction of normal stress in measurement software catman®
Residual stress analysis

- Residual stress: interior forces in material without exterior forces
  - uneven cooling of casted components
  - on weld seam
  - through mechanical processing operation

- Determination of residual stress in material structure with:
  - Layer ablation method
  - Cutting method
  - Hole drilling method
  - Ring-core method
Residual stress analysis

- **Ring-core rosette**
  - Ring-core method: ~4 ...5 mm cutting depth

- **Hole drilling rosette**
  - Hole drilling method: ~1.5 mm drilling depth

Test specimen
Residual stress analysis

- Hole drilling method

MTS3000 from SINT for hole drilling method („high speed drilling method“)

HBM QuantumX MX1615B für den Anschluss der Bohrlochrosetten
Residual stress analysis

- Hole drilling method

MTS3000 from SINT for hole drilling method („high speed drilling method“)
Stress analysis

- Example: pressure-shear experiment on brickwork

TU Dresden Bauingenieurwesen Otto-Mohr-Labor
Financing: Stiftung Frauenkirche, Dresden
Stress analysis

- Example: strain gauge application on Severins bridge in Cologne
Stress analysis

- Example: strain measurement on circuit boards

strain gauge rosette in miniature format (RF9)
### Fields of application – strain gauges

<table>
<thead>
<tr>
<th>Experimental tests</th>
<th>Transducer manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Experimental stress analysis</td>
<td>- Force</td>
</tr>
<tr>
<td>- Residual stress analysis</td>
<td>- Mass</td>
</tr>
<tr>
<td>- Analysis of loading</td>
<td>- Torque</td>
</tr>
<tr>
<td>- Life-time analysis</td>
<td>- Pressure</td>
</tr>
<tr>
<td>- Determining thermal stress</td>
<td>- Strain</td>
</tr>
</tbody>
</table>

- Experimental stress analysis
- Residual stress analysis
- Analysis of loading
  - Life-time analysis
- Determining thermal stress
- Force
- Mass
- Torque
- Pressure
- Strain
Transducer manufacturing
Transducer manufacturing
HBM Academy

More information can be found on our website:

HBM Academy Seminars and Trainings

Learning, practicing and understanding: The HBM Academy offers seminars and trainings for all knowledge levels from beginner to measurement application professional.

In three steps to the successful measurement result – with the HBM Academy

Measurement data are the key to further develop your products. In the seminars of the HBM Academy, our trainers and measurement technicians accompany you on the way to the “right” result: from the selection and installation of the sensor system, the safe measurement data acquisition, to the evaluation and evaluation of your results.

- **Starter seminars** in which we highlight the most important “basics” of measurement technology to obtain reliable results. Basic, but important!
- **Advanced seminars** for different measurands and sensor technology (e.g. strain gauge installation, torque measurement, weighing technology). Let’s go into details
- **Expert seminars** for the use of the entire measurement chain from sensor to software, and on complex measurement setups.

- Annually more than 5,000 satisfied seminar participants worldwide
- More than 95 percent of our seminar participants recommend us!
- All seminar topics specially designed for measurement engineers and users of measurement technology. A unique offer worldwide!
Additional information (knowledge transfer)

More information can be found on our website:

Additional information (products)

More information can be found on our website:

Additional information

Upcoming webinars and more information:

- [www.hbm.com/webinars](http://www.hbm.com/webinars)

Webinars - live and on-demand

Grow your knowledge and skills with our free live and on-demand webinars.
Any questions?

- If you have any questions, please do not hesitate to contact us: webinar@hbm.com

- Or email the presenter directly: dirk.eberlein@hbm.com
www.hbm.com

Dirk Eberlein
M-TMS, HBM GmbH
Tel. +49 6151 803 – 763
dirk.eberlein@hbm.com