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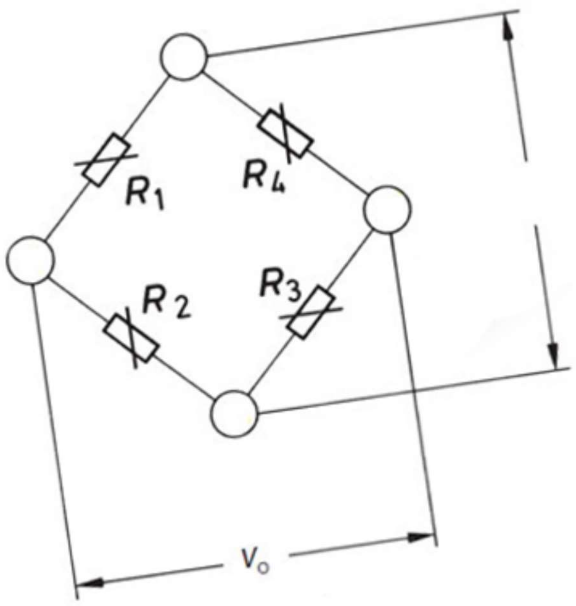
The Wheatstone Bridge Circuit Explained

Learn the basics and theory of operation



The Wheatstone Bridge Circuit

The Wheatstone bridge can be used in various ways to measure electrical resistance:

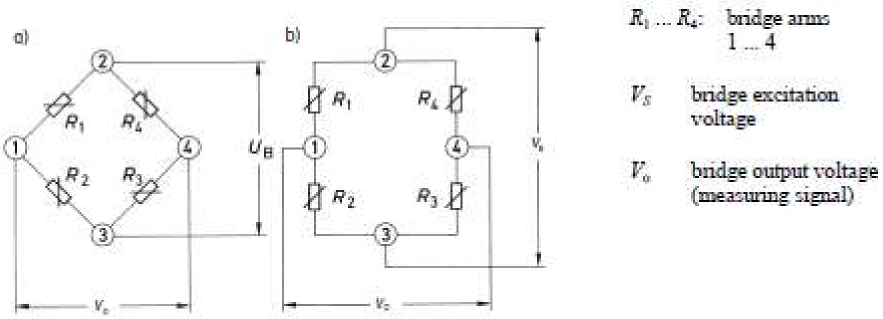
- For the determination of the absolute value of a resistance by comparison with a known resistance
- For the determination of relative changes in resistance

The latter method is used with regard to strain gauge techniques. It enables relative changes of resistance in the strain gauge, which are usually around the order of 10^{-4} to 10^{-2} Ω/Ω to be measured with great accuracy.

The image below shows two different illustrations of the Wheatstone bridge which are electrically identical: figure a) shows the usual rhombus representation in which the Wheatstone is used; and figure b) is a representation of the same circuit, which will be clearer for an electrically untrained person.

The four arms or branches of the bridge circuit are formed by the resistances R_1 to R_4. The corner points 2 and 3 of the bridge designate the connections for the bridge excitation voltage V_S; the bridge output voltage V_0 , that is the measurement signal, is available on the corner points 1 and 4.

The bridge excitation is usually an applied, stabilized direct, or alternating voltage V_S.



Note:
There is no generally accepted rule for the designation of the bridge components and connections. In existing literature, there are all kinds of designations and this is reflected in the bridge equations. Therefore, it is essential that the designations and indices used in the equations are considered along with their positions in the bridge networks in order to avoid misinterpretation.

If a supply voltage V_s is applied to the bridge supply points 2 and 3, then the supply voltage is divided up in the two halves of the bridge R_1, R_2 and R_4, R_3 as a ratio of the corresponding bridge resistances, i.e., each half of the bridge forms a voltage divider.

The bridge can be imbalanced, owing to the difference in the voltages from the electrical resistances on R_1, R_2 and R_3, R_4. This can be calculated as follows:

$$V_O = V_S\left(\frac{R_1}{R_1 + R_2} - \frac{R_4}{R_3 + R_4}\right)$$

if the bridge is balanced and

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

where the bridge output voltage V_0 is zero.

With a preset strain, the resistance of the strain gauge changes by the amount ΔR. This gives us the following equation:

$$V_O = V_S\left(\frac{R_1+\Delta R_1}{R_1+\Delta R_1+R_2+\Delta R_2}-\frac{R_4+\Delta R_4}{R_3+\Delta R_3+R_4+\Delta R_4}\right)$$

For strain measurements, the resistances R_1 and R_2 must be equal in the Wheatstone bridge.
The same applies to R_3 and R_4.

With a few assumptions and simplifications, the following equation can be determined (further explanations are given in the HBM book "An Introduction to Measurements using Strain Gauges"):

$$\frac{V_O}{V_S}=\frac{1}{4}\left(\frac{\Delta R_1}{R_1}-\frac{\Delta R_2}{R_2}+\frac{\Delta R_3}{R_3}-\frac{\Delta R_4}{R_4}\right)$$

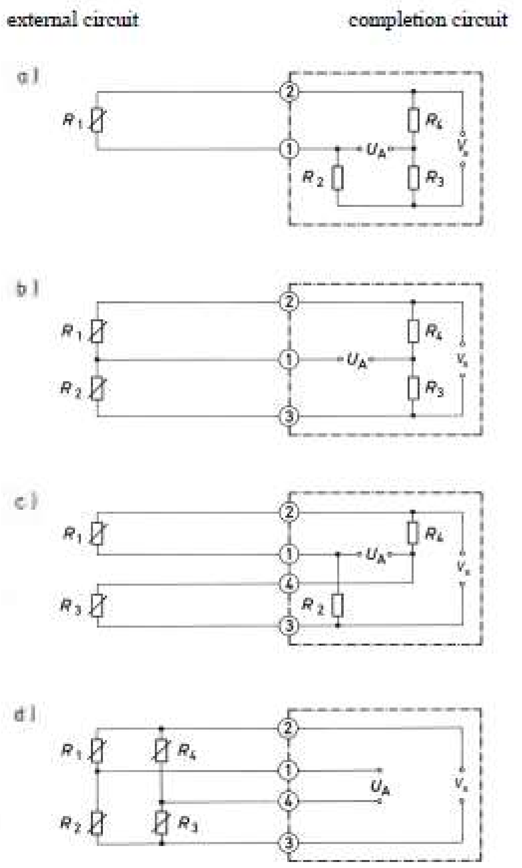
In the last step of calculation, the term ΔR/R must be replaced by the following:

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

Here k is the k-factor of the strain gauge, ε is the strain. This gives us the following:

$$\frac{V_O}{V_S}=\frac{k}{4}(\varepsilon_1-\varepsilon_2+\varepsilon_3-\varepsilon_4)$$

The equations assume that all the resistances in the bridge change. For instance, this situation occurs in transducers or with test objects performing similar functions. In experimental tests, this is hardly ever the case and usually only some of the bridge arms contain active strain gauges, the remainder consisting of bridge completion resistors. Designations for the various forms, such as quarter bridge, half bridge, double quarter or diagonal bridge and full bridge, are commonplace.



Forms of the Wheatstone bridge circuit used in strain gage techniques
a) quarter bridge
b) half bridge
c) double quarter or diagonal bridge
d) full bridge

Depending on the measurement task one or more strain gauges are used at the measuring point. Although designations such as full bridge, half bridge ,or quarter bridge are used to indicate such arrangements, actually they are not correct. In fact, the circuit used for the measurement is always complete and is either fully or partially formed by the strain gauges and the specimen. It is then completed by fixed resistors, which are incorporated within the instruments.

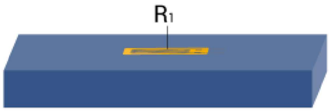
Transducers generally have to comply with more stringent accuracy requirements than measurements pertaining to experimental tests. Therefore, transducers should always have a full bridge circuit with active strain gauges in all four arms.

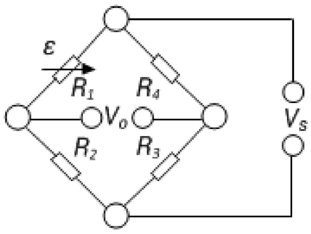
Full bridge or half bridge circuits should also be used for stress analysis if different kinds of interferences need to be eliminated. An important condition is that cases of different stresses are clearly distinguished, such as compressive or tensile stress, as well as bending, shear, or torsional forces.

The table below shows the dependence of the geometrical position of the strain gauges, the type of bridge circuit used and the resulting bridge factor B for normal forces, bending moments, torque and temperatures. The small tables given for each example specify the bridge factor B for each type of influencing quantity. The equations are used to calculate the effective strain from the bridge output signal V_O/V_S.

	Bridge configuration		External impacts measured:	/

1





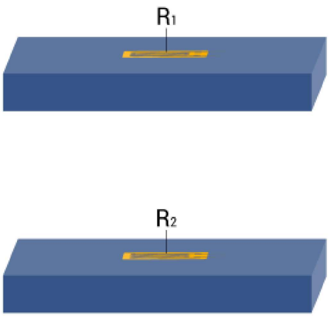
$$\varepsilon = \varepsilon_n + \varepsilon_b = \frac{4}{k} \cdot \frac{V_O}{V_S} - \varepsilon_s$$

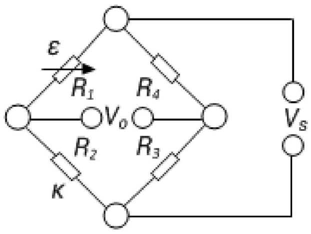
T	Fn	Mb	Md
1	1	1	0

Strain n
a tensic
bar

Strain n
a bendi

2





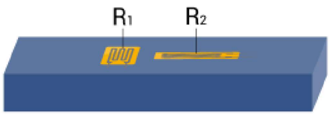
$$\varepsilon = \varepsilon_n + \varepsilon_b = \frac{4}{k} \cdot \frac{V_O}{V_S}$$

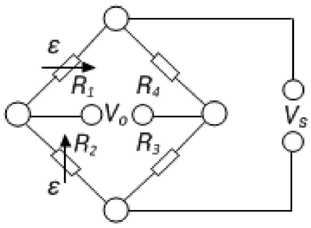
T	Fn	Mb	Md
0	1	1	0

Strain n
a tensic
bar

Strain n
a bendi

3





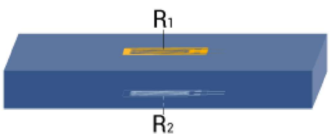
$$\varepsilon = \varepsilon_n + \varepsilon_b = \frac{1}{(1+\nu)} \cdot \frac{4}{k} \cdot \frac{V_O}{V_S}$$

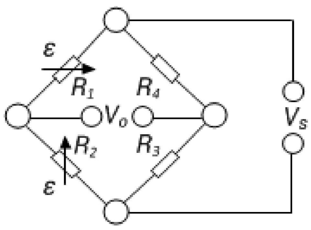
T	Fn	Mb	Md
0	1+ν	1+ν	0

Strain n
a tensic
bar

Strain n
a bendi

4



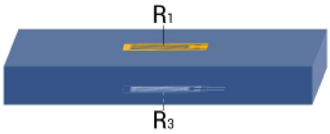


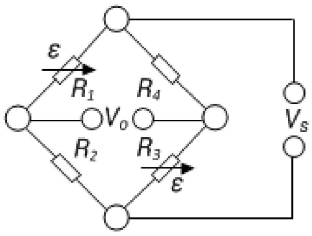
$$\varepsilon = \varepsilon_b = \frac{1}{2} \cdot \frac{4}{k} \cdot \frac{V_O}{V_S}$$

T	Fn	Mb	Md
0	0	2	0

Strain n
a bendi

5



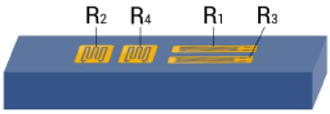


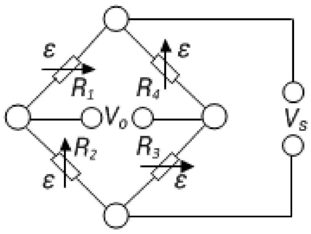
$$\varepsilon = \varepsilon_n = \frac{1}{2} \cdot \frac{4}{k} \cdot \frac{V_O}{V_S} - \varepsilon_s$$

T	F_n	M_b	M_d
2	2	0	0

Strain n
a tensic
bar

6





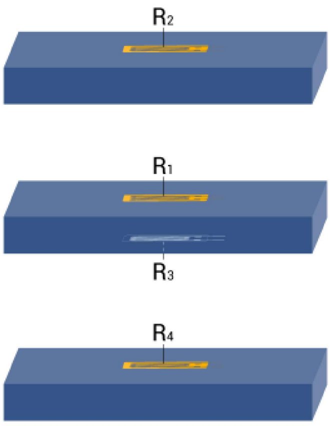
Strain n
a tensic
bar

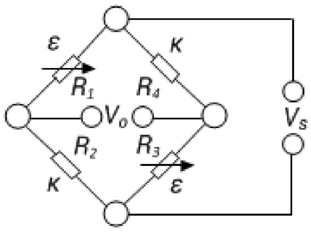
$$\varepsilon = \varepsilon_n + \varepsilon_b = \frac{1}{2(1+\nu)} \cdot \frac{4}{k} \cdot \frac{V_O}{V_S}$$

Strain n
a bendi

T	F_n	M_b	M_d
0	2(1+ν)	2(1+ν)	0

7



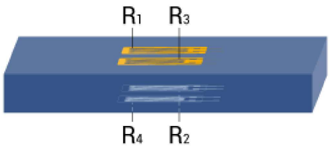


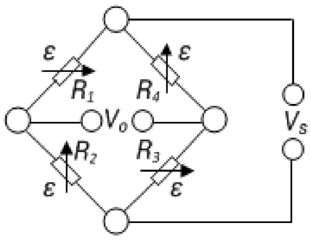
$$\varepsilon = \varepsilon_n = \frac{1}{2} \cdot \frac{4}{k} \cdot \frac{V_O}{V_S}$$

T	F_n	M_b	M_d
0	2	0	0

Strain n
a tensic
bar

8



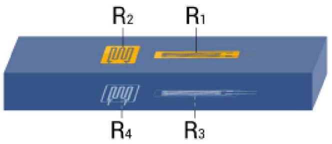


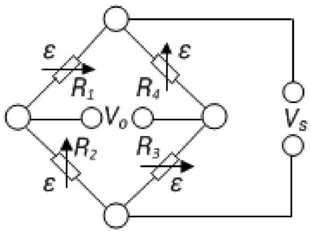
$$\varepsilon = \varepsilon_b = \frac{1}{4} \cdot \frac{4}{k} \cdot \frac{V_O}{V_S}$$

T	F_n	M_b	M_d
0	0	4	0

Strain n
a bendi

9



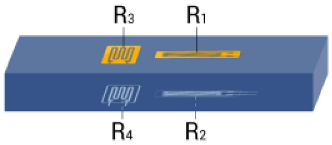


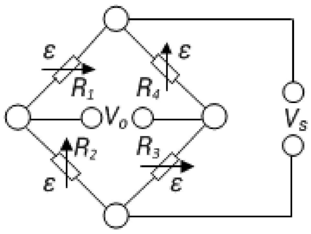
$$\varepsilon = \varepsilon_n = \frac{1}{2(1+\nu)} \cdot \frac{4}{k} \cdot \frac{V_O}{V_S}$$

T	F_n	M_b	M_d
0	2(1+ν)	0	0

Strain n
a tensic
bar

10



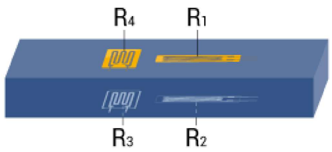


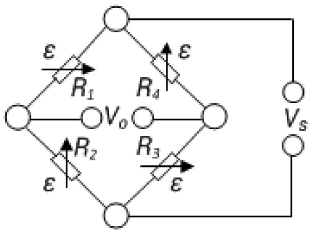
$$\varepsilon = \varepsilon_b = \frac{1}{2(1-\nu)} \cdot \frac{4}{k} \cdot \frac{V_O}{V_S}$$

T	F_n	M_b	M_d
0	0	2(1-ν)	0

Strain n
a bendi

11



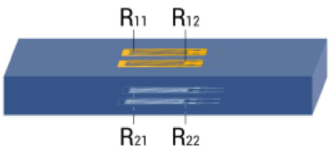


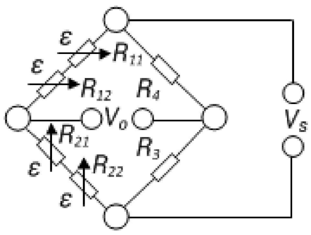
$$\varepsilon = \varepsilon_n = \frac{1}{2(1+\nu)} \cdot \frac{4}{k} \cdot \frac{V_O}{V_S}$$

T	F_n	M_b	M_d
0	0	2(1+ν)	0

Strain n
a bendi

12



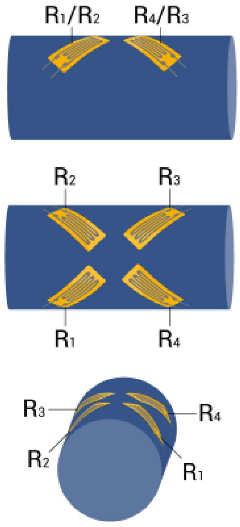


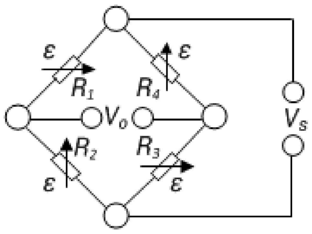
$$\varepsilon = \varepsilon_b = \frac{1}{2} \cdot \frac{4}{k} \cdot \frac{V_O}{V_S}$$

T	F_n	M_b	M_d
0	0	2	0

Strain n
a bendi

13



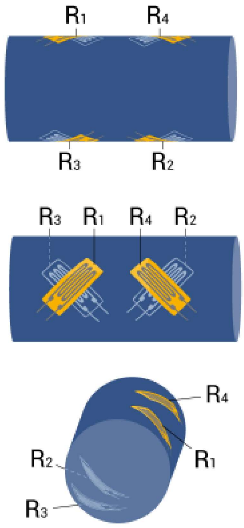


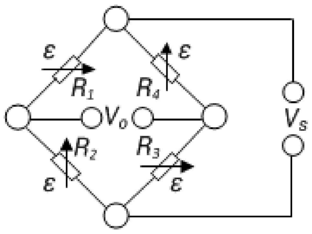
$$\varepsilon = \varepsilon_d = \frac{1}{4}\cdot\frac{4}{k}\cdot\frac{V_O}{V_S}$$

T	F_n	M_{bx}	M_{by}	M_d
0	0	0	0	4

Measur
strain

14



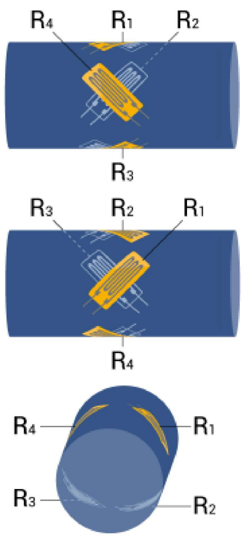


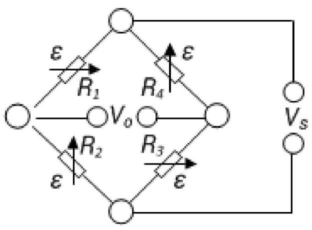
$$\varepsilon = \varepsilon_d = \frac{1}{4}\cdot\frac{4}{k}\cdot\frac{V_O}{V_S}$$

T	F_n	M_{bx}	M_{by}	M_d
0	0	0	0	4

Measur
strain w
space f

15





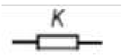
$$\varepsilon = \varepsilon_d = \frac{1}{4}\cdot\frac{4}{k}\cdot\frac{V_O}{V_S}$$

T	F_n	M_{bx}	M_{by}	M_d
0	0	0	0	4

Measur
strain w
space f

Note:
A cylindrical shaft is assumed for torque measurement in example 13, 14, and 15. For reasons related to symmetry, bending in X and Y direction is allowed. The same conditions also apply for the bar with square or rectangular cross sections.

Explanations of the symbols:

T	Temperature
F_n	Normal force
M_b	Bending moment
M_{bx}, M_{by}	Bending moment for X and Y directions
M_d	Torque
ε_s	Apparent strain
ε_n	Normal strain
ε_b	Bending strain
ε_d	Torsion strain
ε	Effective strain at the point of measurement
v	Poisson’s ratio
	Active strain gauge
	Strain gauge for temperature compensation
	Resistor or passive strain gauge

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Language

Title / Description	Language
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