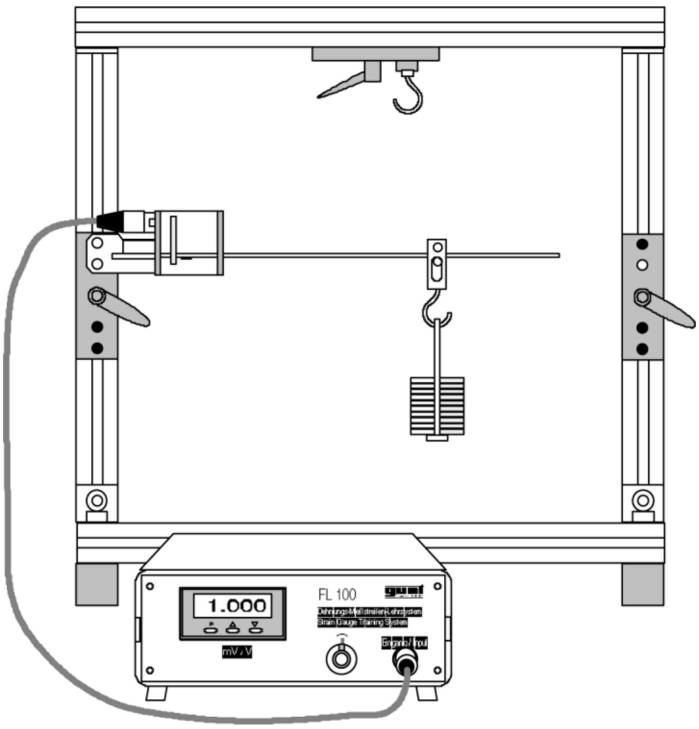
الجامعة الدولية للرباط
Université Internationale de Rabat

School of Aerospace Engineering

School of Automotive Engineering

Laboratory 4

Measure of Stress and Strain Using Strain Gauge System



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Contents

1. Objectives:

To have comprehensive introduction to the fundamentals of strain-gauge technology, permitting investigation of the simple mechanical load situations tension/compression, bending and torsion. The values measured in the course of the experiment can be compared to the theoretical levels. The basics of practical use, such as application of the gauge or connection to form a measuring bridge can be readily incorporated into the training concept.

In this experiment, the student study the effect of type magnitude of loading, and the material on the developed stress and strain using strain gauges.

2. Introduction:

Strain gauges permit simple and reliable determination of stress and strain distribution at real components under load.

The strain-gauge technique is thus an indispensable part of experimental stress analysis. Wide-spread use is also made of strain gauges in sensor construction (scales, dynamometers and pressure gauges, torque meters).

All test objects are provided with a full-bridge circuit and are ready wired. A perspex cover protects the element whilst giving a clear view. The test objects are inserted in a frame and loaded with weights.

The measuring amplifier has a large bright digital LED display, which is still easy to read from a distance. The unit is thus also eminently suited to demonstration experiments.

3. Equipment description:

The equipment contains of

a. Loading frame:

The loading frame is made of light-alloy sections and serves to accommodate the different test objects. Various holders (1) are attached to the frame for this purpose. Clamping levers enable these holders to be quickly and easily moved in the grooves of the frame and fixed in position.

The training system is provided with two different sets of weights for loading the test objects.

- Small set of weights (2) 1 - 6 N, graduations 0.55 N for bending experiments

- Large set of weights (3) 5 - 50 N, graduations 5 N for torsion and tensile experiments.

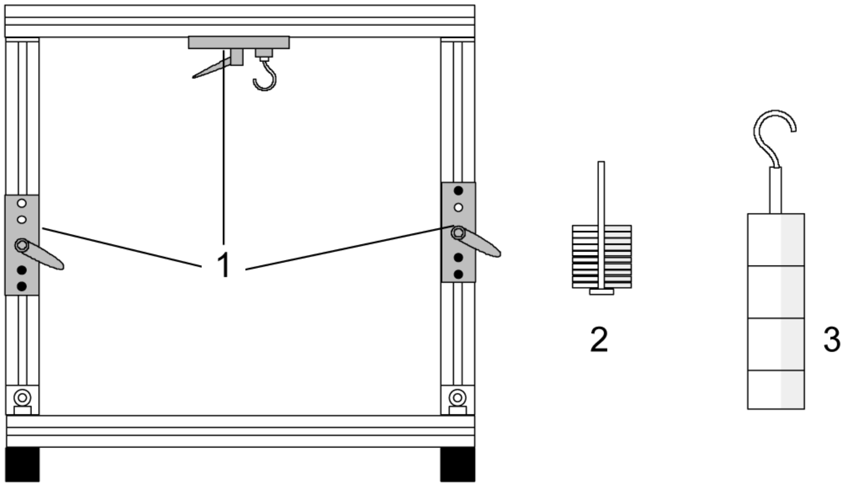


Fig. 4.1 Loading frame

b. Test objects: Bending beam

The test object used for bending experiments is a clamped steel cantilever beam (4).

The strain-gauge element (2) (full-bridge circuit) is attached in the vicinity of the clamping point. Electrical connection is by way of a small PCB and a 5-pin socket (1) with bayonet lock. The strain-gauge configuration can be seen from the adjacent diagram.

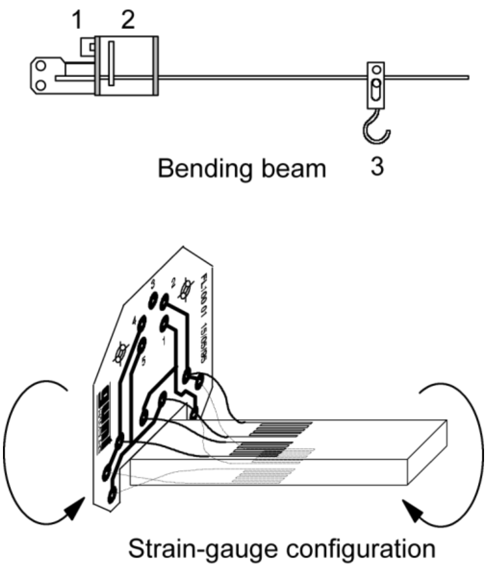


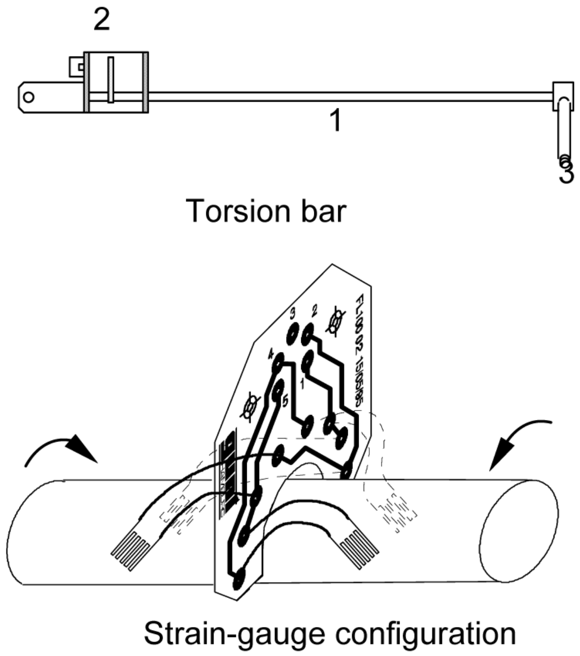
Fig. 4.2 Test objects: Bending beam

The element is protected by a perspex housing. An adjustable slider (3) with hook permits loading with a single force at a defined lever arm.

c. Test objects: Torsion beam

The test object used for torsion experiments is a clamped round steel bar (1).

As with the bending beam, the strain-gauge element (2) is located in a perspex housing. A trans- verse lever (3) is attached to the free end of the torsion bar to generate the torsional moment. The lever arm is 100 mm. To suppress unwanted ben- ding moments or lateral forces, the free end is supported at the loading frame. Configuration of the strain gauges in the form of a 45° full bridge is shown in the adjacent diagram.



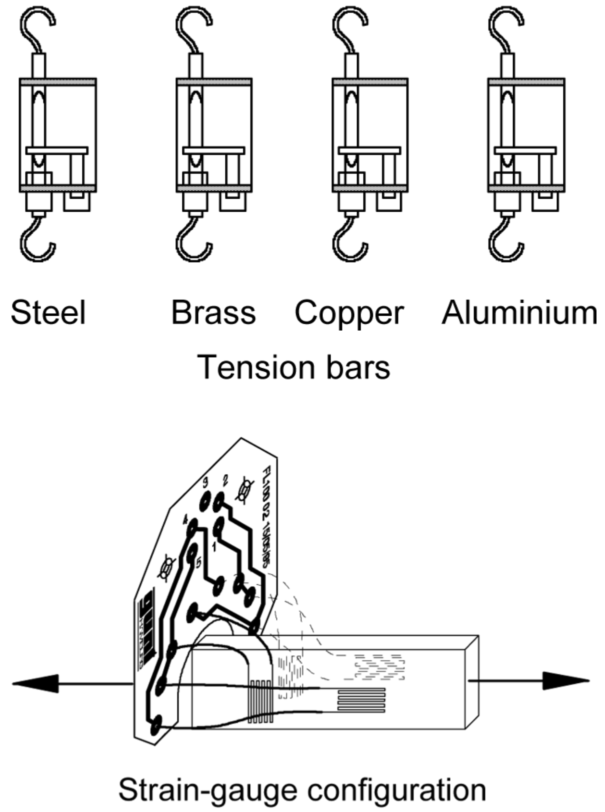


Fig. 4.3 Test objects : Torsion beam

Fig. 4.4 Test objects : Tension beam.

d. Test objects: Tension beam

The test objects used for tensile experiments are available in four different materials.

- \- Steel
- FL100.01 Brass
- FL100.02 Copper
- FL100.03 Aluminum

Both ends of the tension bars are provided with hooks for introduction of the tensile forces.

The tension bars feature a strain-gauge full bridge. As with the test objects for bending and torsion, the elements are protected by a perspex housing. Configuration of the strain gauges in the form of a full bridge with two gauges each for linear and transverse strain is shown in the adjacent diagram.

e. Measuring amplifier

The measuring amplifier with digital 4-position LED display (1) gives a direct indication of the bridge unbalance in mV/V. The connected strain-gauge bridge can be balanced by way of a ten-turn potentiometer (2).

- Range: 2.000 mV/V
- Resolution: 1 V/V.
- Balancing range: 1.0 mV/V.
- Nominal strain-gauge resistance: 350
- Strain-gauge feed voltage :10V
- Power supply: 230V / 50Hz

The unit is envisaged for the connection of strain-gauge full bridges.

The test objects are connected by way of the cable (4) supplied to the 7-pin input socket (3) on the front. The pin assignment is shown on the left.

The measuring amplifier is mains-operated.

The mains switch (5) and the fuses (6) are located on the back.

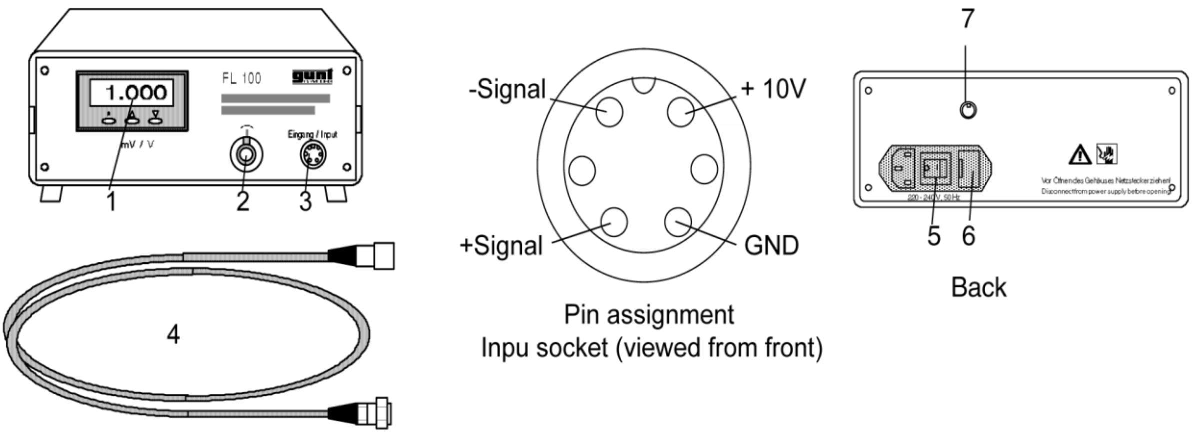


Fig. 4.5 Measuring amplifier

4. Formula Symbols and Units Used

Symbol	Mathematical/physical quantity	Unit
L	Length	mm
A	Cross section	mm^2
W_y	Section modulus of bending	mm^3
E	Elasticity modulus	N/mm^2
D , d	Diameter	mm
W_p	Section modulus of torsion	mm^3
G	Shear modulus	N/mm^2
k	Gauge factor	Nm/rad
R	Resistance	Ω
ΔR	The change of Resistance	Ω
ε	Strain	% ($\mu\varepsilon$)
σ	Tensile Stress	N/mm^2
τ	Shear Stress	N/mm^2
F	Tensile Forces, Normal Force	N
U_A	Output Voltage	V
U_E	Feed voltage	V
ν	Poisson's ratio	-
M_b	Bending Moment	Nm
b	width	mm
h	height	mm
γ	shear	% ($\mu\varepsilon$)
M_t	Torsional Moment	Nm

5. Coefficients and specimen's characteristics

a. Bending beam

- Material: Steel
- Length L: 385 mm
- Cross section A: 4.75 x 19.75 mm2
- Section modulus of bending Wy: 74.26 mm3
- Modulus of elasticity E: 210000 N/mm2
- Poisson's ratio ν : 0.28

b. Torsion beam

- Material: Steel
- Length L: 500 mm
- Diameter D: 10 mm
- Section modulus of torsion Wp: 196.3 mm3
- Shear modulus G: 80000 N/mm2
- Poisson's ratio ν : 0.28

c. Tension beam

Table 4.1 Material specifications

	Bar 1	Bar 2	Bar 3	Bar 4
Reference	-	FL100.01	FL100.02	FL100.03
Material	Steel CrNi 18.8	Brass	Copper	Aluminum
Cross section [mm2]	10 x 2	10 x 2	10 x 2	10 x 2
E [GPa]	191	88	123	69
Poisson's ratio ν	0.305	0.33	0.33	0.33

d. Strain gauges

The constantan strain gauges used have a k-factor of 2.05.

6. Safety Instructions

ATTENTION	ATTENTION Be attention when connect up the 5-pin and 7-pin input sockets, they must be in a good orientation according to amplifier or bars connectors.
ATTENTION	ATTENTION The test bars would be ruined by plastic deformation and thus become unusable. The bending beam in particular should not be subjected to a load of more than $6.5\ N$, therefore, load bending beam with small set of weights; the torsion bar should not be subjected to a load of more than $20\ N$, therefore, load torsion bar with large set of weights; the tension bars can't be subjected to a load of more than $50\ N$, therefore, load torsion bar with large set of weights.

7. Basic principles

a. Principle of strain-gauge technique

When dimensioning components, the loads to be expected are generally calculated in advance within the scope of design work and the components then dimensioned accordingly.

It is often of interest to compare the loads subsequently encountered in operation to the design forecasts. Precise knowledge of the actual load is also of great importance for establishing the cause of unexpected component failure.

The mechanical stress is a measure of the load and a factor governing failure. This stress cannot generally be measured directly. As however the material strain is directly related to the material stress, the component load can be determined by way of strain measurement. An important branch of experimental stress analysis is based on the principle of strain measurement.

The use of the strain-gauge technique enables strain to be measured at the surface of the component. As the maximum stress is generally found at the surface, this does not represent a restriction.

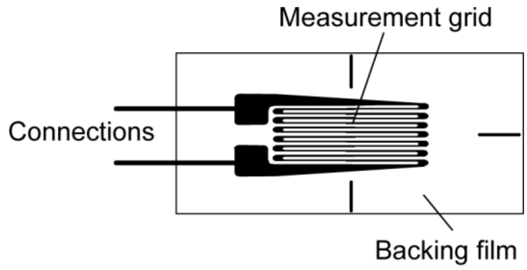


Fig. 4.6 Foil-type strain gauge (greatly enlarged)

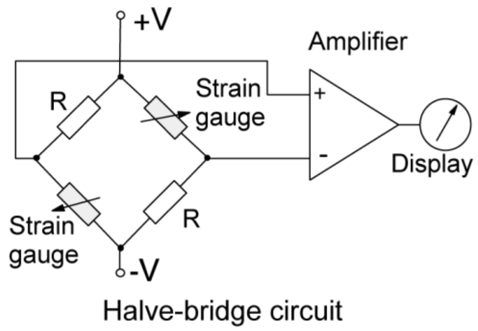
With metallic strain gauges, the type most frequently employed, use is made of the change in the electrical resistance of the mechanically strained thin metal strip or metal wire.

The change in resistance is the combination of tapering of the cross-sectional area and a change in the resistivity. Strain produces an increase in resistance.

To achieve the greatest possible wire resistance with small dimensions, it is configured as a grid. The ratio of change in resistance to strain is designated k

$$k = \frac{\Delta R / R_0}{\varepsilon} \qquad \textbf{Eq. 4.1}$$

Strain gauges with a large k-factor are more sensitive than those with a small one.



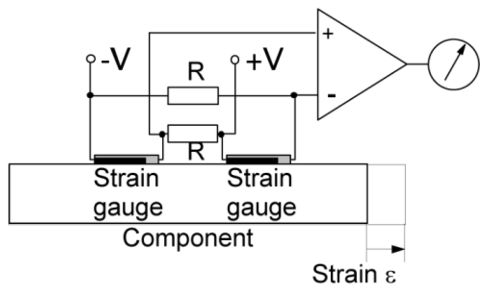


Fig. 4.7 Configuration of half bridge on component

In order to be able to assess the extremely small change in resistance, one or more strain gauges are combined to form a Wheatstone bridge, which is supplied with a regulated DC voltage (V).

The bridge may be fully (full bridge) or only partially (half and quarter bridge) configured with active strain gauges. The resistors R required to complete the bridge are called complementary resistors. The output voltage of the bridge reacts very sensitively to changes in resistance in the bridge branches. The voltage differences occurring are then amplified in differential amplifiers and displayed.

The design of a strain gauge is shown in the adjacent illustration. The wave-form metal strips are mounted on a backing material, e.g. a thin elastic polyimide film and covered with a protective film. Today's metal strips are usually produced by etching from a thin metal foil (foil-type strain gauges). Thin connecting wires are often welded directly to the strain gauge.

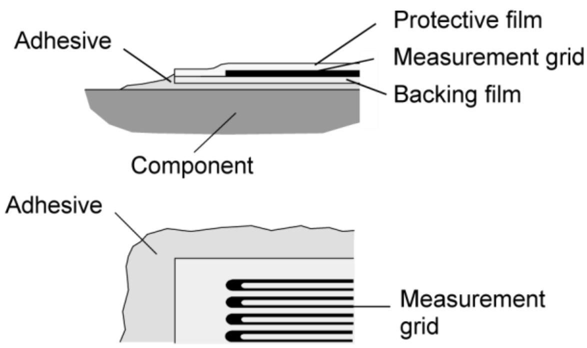


Fig. 4.8 Design of strain gauge

The strain gauge is bonded to the component with a special adhesive, which must provide loss-free transmission of the component strain to the strain gauge.

b. Tension or compression Fundamentals

Tension or compression is the simplest form of loading. Homogeneous stress forms in the tensile specimen. The stresses at the surface, where they can be measured with strain gauges, are of precisely the same magnitude as the internal stresses.

Tensile stress σ is calculated from tensile force (normal force) F and cross-sectional area A

$$\sigma = \frac{F}{A} \qquad \textbf{\textit{Eq. 4.2}}$$

According to Hooke's law stress and strain ε are linked to one another by way of the modulus of elasticity E

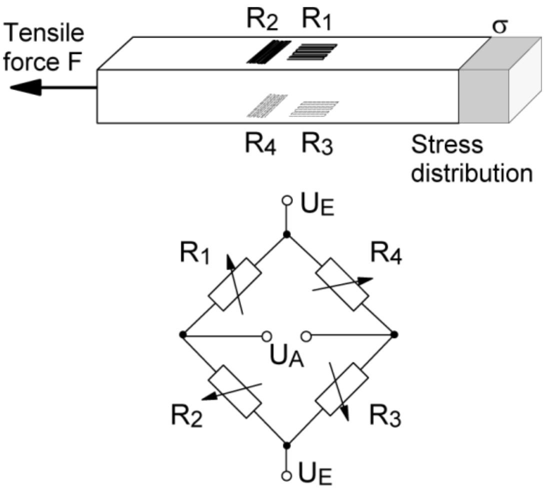


Fig. 4.9 Tension configuration

$$\sigma = E.\varepsilon \qquad \textbf{Eq. 4.3}$$

For experimental determination of the tensile stress, two strain gauges each are fitted to the front and back of the specimen; one strain gauge is attached in longitudinal, the other in transverse direction. The strain gauges on each side form a branch of the bridge. Such a configuration is characterized by the following: Utilization of linear and transverse strain increases sensitivity.

Thanks to the arrangement on opposite sides, superimposed bending stresses have no influence on the measurement result. The output signal U_A of the measuring bridge is referenced to the feed voltage U_E. The sensitivity k of the strain gauge enables the strain to be calculated for the full bridge as follows

$$\varepsilon = \frac{1}{2.(1+\nu)}.\frac{4}{k}.\frac{U_A}{U_E} \qquad \textbf{Eq. 4.4}$$

Where ν is Poisson's ratio for the respective material (Table 4.1)?

c. Bending Fundamentals

The stress at the surface of the bending beam can be calculated from the bending moment M_b and the section modulus Wy

$$\sigma = \frac{M_b}{W_y} \qquad \textbf{Eq. 4.5}$$

Bending moment calculated for cantilever beam

$$M_b = -F.L \qquad \textbf{Eq. 4.6}$$

Where F is the load and L the distance between the point at which the load is introduced and the measurement point. The section modulus for the rectangular cross section of width b and height h is

$$W_y = \frac{b.h^2}{6} \qquad \textbf{Eq. 4.7}$$

For experimental determination of the bending stresses, the bending beam is provided with two strain gauges each on the compression and tension sides. The strain gauges of each side are arranged diagonally in the bridge circuit. This leads to summation of all changes in resistance and a high level of sensitivity. The output signal UA of the measuring bridge is referenced to the feed voltage UE. The sensitivity k of the strain gauge enables the strain to be calculated for the full bridge as follows

$$\varepsilon = \frac{1}{k}.\frac{U_A}{U_E} \qquad \textbf{Eq. 4.8}$$

According to Hooke's law the stress being sought is obtained with the modulus of elasticity E

$$\sigma = E.\varepsilon \qquad \textbf{Eq. 4.9}$$

d. Torsion or compression Fundamentals

One area of application of strain-gauge technology is the measurement of torsional moments in shafts, where the torque in the shaft is calculated from the shear stress measured.

For experimental determination of the torsional stress, the torsion bar is provided with four strain gauges at an angle of 45°. The strain gauges are thus located in the direction of the principal normal stresses and hence the maximum strain. The strain gauges are arranged diagonally in the bridge circuit. This leads to summation of all changes in resistance and a high level of sensitivity. The strain ε can be calculated as follows

$$\varepsilon = \frac{1}{k}.\frac{U_A}{U_E} \qquad \textbf{Eq. 4.10}$$

With pure shear stress the relationship between strain and shear is as follows

$$\gamma = 2.\varepsilon \qquad \textbf{Eq. 4.11}$$

According to Hooke's law the shear stress being sought is obtained with the shear modulus G

$$\tau = \gamma.G = 2.\varepsilon.G \quad \textbf{Eq. 4.12}$$

The relationship between shear stress at the surface of the torsion bar and torsional moment Mt is as follows

$$M_t = \tau.\mathrm{W_p} \quad \textbf{Eq. 4.13}$$

Where W_p is the section modulus of torsion for the circular cross section

$$W_p = \frac{\pi.d^3}{16} \quad \textbf{Eq. 4.14}$$

8. Experimental Procedure

a. Experiment 1: Tension

1. Fit the tension bar in the frame as shown using the holder with hook.
2. Connect up and switch on measuring instrument.
3. Use offset adjuster to balance display.
4. Load bar with large set of weights. Increase load in stages and note down reading.

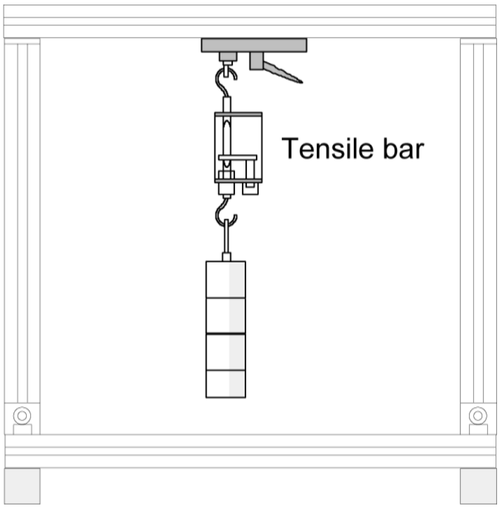


Fig.4.10 Tension experiment

NOTICE

Readings are only very small on account of the weak tensile stresses. Zero balancing is therefore to be performed with extreme care.

b. Experiment 2: Bending

1. Fit bending beam in frame as shown using holder with two pins.
2. Connect up and switch on measuring instrument.
3. Set slider to distance of 250 mm.
4. Use offset adjuster to balance display.
5. Load beam with small set of weights (the suspender weight is 1N) Increase load in steps of 1.1 N (two weights of 0.55) and note down reading.

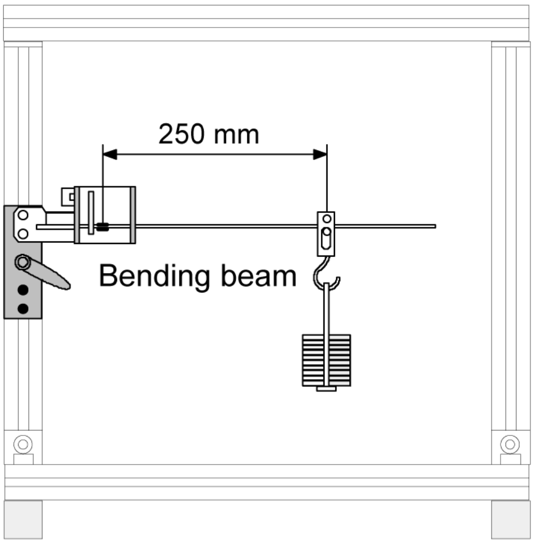


Fig.4.11 Bending experiment

c. Experiment 3: Torsion

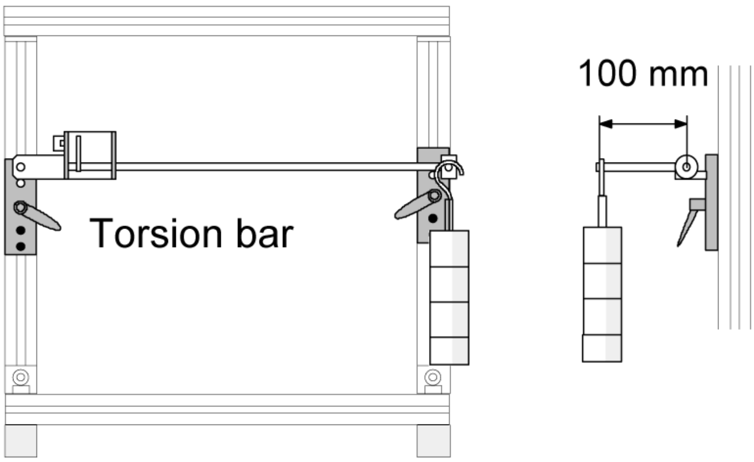


Fig.4.12 Torsion experiment

1. Fit torsion bar in frame as shown. In doing so, place clamping end on upper pin of holder with two pins. Support loose end of bar with another holder. Make sure bar is horizontally aligned.
2. Connect up and switch on measuring instrument.

3. Use offset adjuster to balance display.
4. Suspend set of weights from lever arm and generate torsional moment. Increase load in stages of $5N$ and note down reading.

9. Questions

1- Do the experiment 1 as described in paragraph 7, and note down reading for all tension bars, then compare the measured values of stress (Eq. 4.4, Eq. 4.4 and table 4.1) with those calculated (Eq. 4.4) and plot the relationship between the load and $\frac{U_A}{U_E}$ in a chart.

-Discuss the obtained experimental results and give conclusions.

2- Do the experiment 2 as described in paragraph 7, and note down reading for the bending bar, then compare the measured values of stress (Eq. 4.8, Eq. 4.9 and table 4.1) with those calculated (Eq. 4.5, Eq. 4.6 and Eq. 4.7), and plot the relationship between the load and $\frac{U_A}{U_E}$ in a chart.

-Discuss the obtained experimental results and give conclusions.

2- Do the experiment 3 as described in paragraph 7, and note down reading for the torsion bar, then compare the measured values of stress (Eq. 4.10, Eq. 4.11, Eq. 4.12 and table 4.1) with those calculated (Eq. 4.10, Eq. 4.11, Eq. 4.12 and table 4.1), and plot the relationship between the load and $\frac{U_A}{U_E}$ in a chart.

-Discuss the obtained experimental results and give conclusions.

10. Results

a. Experiment 1: Tension

1- Mathematical calculation

2- Results

Table 4.2 Tensile experiment, steel CrNi18.8

Load N	0	10	20	30	40	50
Reading mV/V						

Table 4.3 Tensile experiment, copper

Load N	0	10	20	30	40	50
Reading mV/V						

Table 4.1 Tensile experiment, brass

Load N	0	10	20	30	40	50
Reading mV/V						

Table 4.1 Tensile experiment, aluminum

Load N	0	10	20	30	40	50
Reading mV/V						

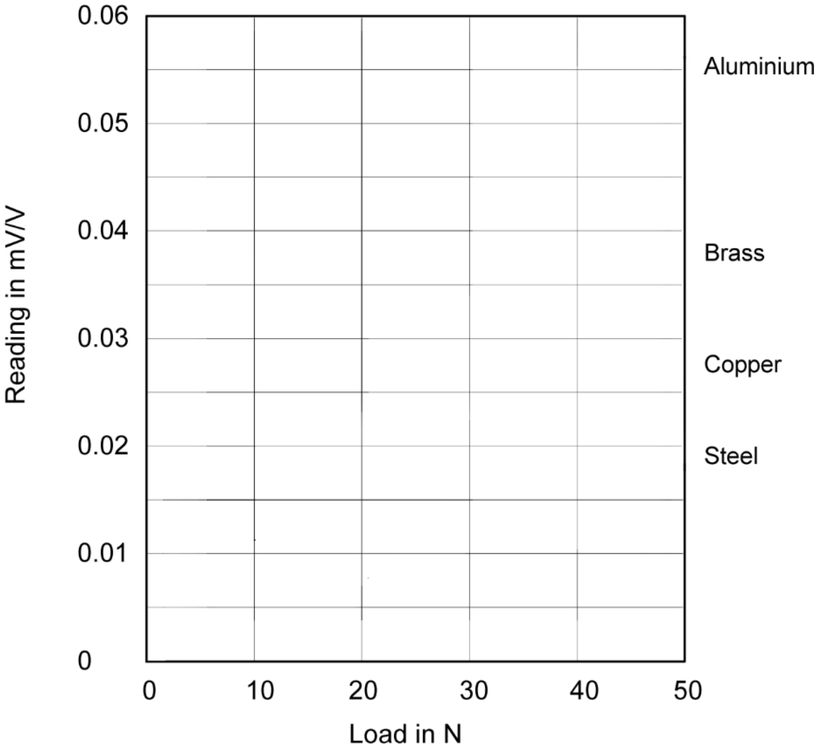


Fig.4.13 Tensile experiment with various materials

Table 4.1. Stresses and strains for a load of 50N, Cross-sectional area 20 mm2

Material	mV/V	Strain 10^{-6}	Stress $N/mm2$	
	Reading	Measured	Measured	Calculated
Steel CrNi18.8				
Copper				
Brass				
Aluminum				

3- Discussion the results and conclusion:

b. Experiment 2: Bending

1- Mathematical calculation

2- Results

Table 4.1 Bending experiment, lever arm 250 mm

Load N	0	1	2.1	3.2	4.3	5.4	6.5
bending moment Nm							
Reading mV/V							
Measured Strain 10^{-6}							
Measured Stress $N/mm2$							
calculated Stress $N/mm2$							

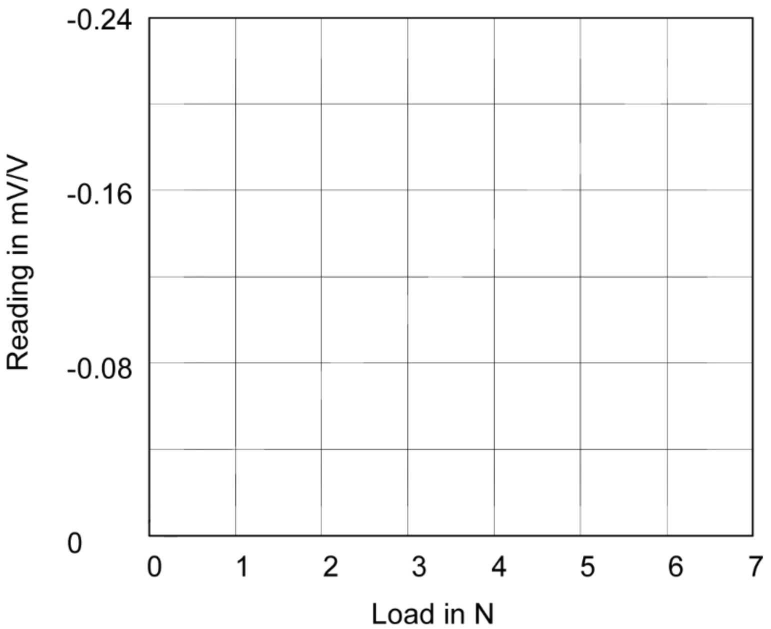


Fig.4.14 Bending experiment

3- Discussion the results and conclusion:

c. Experiment 3: Torsion

1- Mathematical calculation

2- Results

Table 4.1 Torsion experiment, lever arm 100 *mm*

Load N	0	5	10	15	20
Torsional moment Nm					
Reading mV/V					
Measured Strain 10^{-6}					
Measured Stress $N/mm2$					
calculated Stress $N/mm2$					

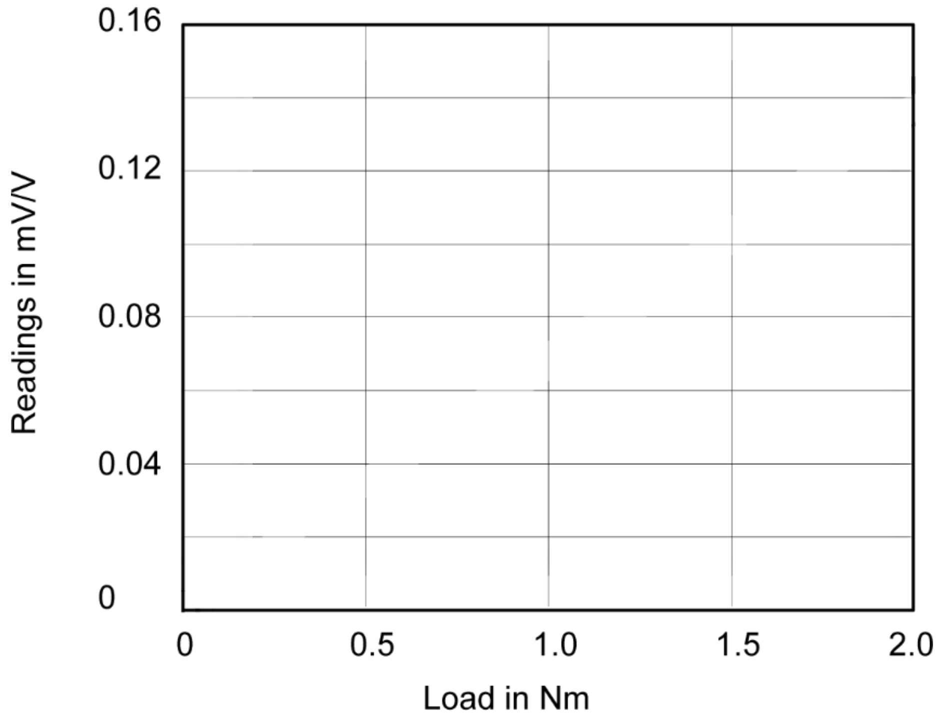


Fig. 4.15 Torsion experiment

3- Discussion the results and conclusion: