Experiment 1 : Linear measurement

$$Accuracy = \frac{\text{1 division main scale}}{\text{number of divisions on the varnier scale}}$$

① Calipers → used to measure (thickness , distance , diameter)

*** Varnier Caliper** = it is a precision instrument used to measure internal & external distances extremely accurate. (it has two scales : main scale and varnier scale)

*** Dial Caliper** = it is a modified varnier caliper with gauges , allows us to have <u>direct</u> reading. It can also provided with digital indicator

→ for the metric dial : one revolution of the hand represents 2mm of travel and each dial graduation represents 0.02 mm max. discrimination [other type 5mm move/rev → 0.05 max.]

→ the beam scale on the dial is graduated only into 5mm and 10mm increment

→ the caliper dial is graduated into 100 dimensions.

NOTE: ABBE's principle ⇒ The maximum accuracy may obtain when the standard scale and the workpiece are aligned on the same Line measurement

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② Micrometers → is a widely used device for measuring (thickness of blocks , outer and inner diameters and depth)

↳ have several over other measuring instruments :
- measures greater precision than calipers , but smaller ranges of lengths
- the micrometers gives more accurate readings than calipers

* Accuracy verification of a micrometer :
- ◆ zero-checking : is the condition where the display of a zero to one-inch micrometer should show zero
- ◆ calibration : process of insuring the accuracy of gages (the process involve gage block and micrometer)
  - ↳ If the reading you get from micrometer = gage block's dimension you may begin

The types of micrometers:

1- External micrometers → used to measure wires, spheres , shafts , blocks

2- Internal micrometers → used to measure opening of holes

3- Depth micrometers → used to measure depths of slots and steps

---

Discussion:

Q1: does varnier caliper conform to ABBE's law ? NO, the varnier caliper doesn't conform

Q2: Calculate the error of varnier caliper ? the reading error = $\frac{1}{20}$ = 0.05 mm

Q3: what is the function of the sliding blade of caliper ? permits the dial caliper to be used as an efficient and accurate depth gauge

Q4: what is a direct reading instrument ? does that apply to the caliper ? direct devices are used to measure dimensions directly (there is no other reference devices)
→ the varnier caliper is a direct reading instrument.

Q:5 what are the source of error in reading a caliper ? Reading error / parallax error / error when transferring reading

Q6: what could happen if the Locking screw is not used when measuring a distance ?
the element will not be locked in position Leading to inaccurate reading

Q7: Is the Reading taken from caliper ~~of~~ inside measurement is final ? is it considered as a comparator ?
~~yes~~ NO it is final reading / we can (not) consider it as comparator.

Q8: Is the varnier Line standard or End standard ?

Q9: what are the advantages of varnier caliper over a micrometer ?
- Scales are easier to move
- more convenient and easier to use
- more adaptable
- greater ranges of lengths to measure
- able to measure thickness, length, diameter, depth in the same instruments

Q10: how many screw threads are in each micrometer? the spindle has 2 threads

Q11: does the external micrometer obey's ABBE's law ? yes it obey's ABBE's law

Q12: what is the total length approached by the moving barrel when it rotates a complete revolution? 0.5 mm

Q13: Can micrometers be used as comparators ? yes it can be used

Q14: does the accuracy of micrometer depend on the accuracy of the screw thread ? yes

Q15: What are the sources of error in reading a micrometer ?
- parallax error = not looking perpendicular to the micrometer
- Excessive measuring force
- unclean micro meter
- over tightening the micro meter

Q16: Is the spindle rotating or non-rotating ? Name disadvantages of rotating type?
- it is rotating
- the disadvantages (more expensive, rotating head type exerts a twisting action on work piece)

Experiment 2: Block Gauges → we use them when the maximum accuracy needed

Block gauges → are practical length standards of industry.

→ ① Line standard or Engraved scale = the unit length is defined as being the distance suitably engraved Lines (Like the ruler) (the whole distance is devided into sub units)

→ ② End standard = the unit of length is defined as being the distance between the end faces of the standard (the form of either slip) → (it is more accurate) ※

our experiment is talking about Gauge blocks → they are good examples of end standard

→ Sets of standard blocks or bars have the desired measurement, we use them to build a specific length

→ The characteristics of Gauge blocks: ① they are highly accurate

② they have a built in datum (their faces are flat and parallel)

③ the accuracy of end and line standard is affected by the temperature → They are calibrated at 20°c

④ They are made in high grade cast steel

* Standard Block gauges: ① made of hardened steel and it is heat treated

② the accuracy = 0.0005 mm ③ 20°c & 1 atm & 60% relative humadity (Calibrated Conditions)

→ they have some characterstics:

① straightness →

② Flatness → the surfaces made by the (lapping) process

③ parallelism → each two surfaces or two Lines are parallel to a very high degree

* grades of gauge blocks:

1- 00
2- Calibration → provides highest level of accuracy
3- 0
4- I
5- II

※ when the grades get larger the tolerance get Larger and the price cheaper

※ the best and most expensive is grade 00

Discussion:

Q1: why do we always choose the minimum number of block?

we want to minimize the tolerance and error to make the measurement more accurate (more blocks = more errors) the minimum blocks the more accuracy and precision.

Q2: why do we care about how the blocks should be attached to other?

because block used to calibrate other devices, we want to obtain accurate and true result Also, the blocks shall be placed at right angles and wiring them with a rotary motion to reduce the amount of surface rubbing

Q3: Suggest applications for block gauges?

they are the main means of length standardization used by industry

they are used as a reference for the calibration of measuring equipment such as (micrometers, sine bars, calipers, and dial indicators)

Experiment 3: Sine bar and angular measurement

① Bevel protractor

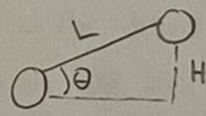
② The plain Bevel protractor → consists from main scale, movable arm and fixed nut.
- its main scale devided into [180] devisions each devision = [1°]
- the accuracy = [±0.5°] and the total revolution can be measured = [180°]

③ Varnier protractor → the [main scale] divided into degrees from 0° to 90° each way
- and the [varnier scale] divided up to that 12 of it's division occupying the same space as 23° on the main scale [1 varnier division = 23/12 = 1.92 degree on main scale]
- this device has movable arm, plate blade, fixed nut and varnier scale
[each division on the varnier scale represents 5′ minutes]

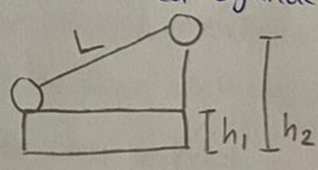
④ The clinometer → special case of the application of the spirit Level.
→ [the main use] the measurement of the included angle of two adjacent faces of a work piece
how to use it? ⊛ the instrument base is placed on one face and rot table body is adjusted until a zero reading of the bubble is obtained and the angle of rotation is then shown on an angular scale moving against an index.
⊛ a second reading is taken on the second face
⇒ main scale = 360°
⇒ varnier scale : full revolution = 1° = 60 min, so each division on varnier scale = 1 min

⑤ Sine bar → it is a hardened steal beam mounted on two hardened cylinders

$$\sin\theta = \frac{\text{side opposite the angle}}{\text{Hypotenuse}}$$



$$\theta = \sin^{-1}\frac{H}{L}$$



$$\theta = \sin^{-1}\frac{h_2-h_1}{L}$$

probable error $d\theta = \pm\left(\frac{dH}{H} + \frac{dL}{L}\right)\tan\theta$

⇒ To insure that the compound angle error is not introduced: the axis of the work must always be parallel to the axis of the sine bar

Discussion:

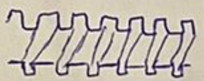
Q: would you use the sine bar for one component or on a production Line?
I would not use the sine bar for a production Line because it would be difficult. using other equipment like clinometer or varnier protractor would be easier.

Experiment 4 : Screw Thread Inspection

* Thread pitch = axial distance from one thread groove to the next groove along the same lin[e]
(p is measured by steel rule, caliper or comparator)

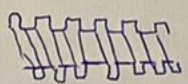
$$p = \frac{\text{number of thread counted}}{\text{Length}}$$

* Left hand Thread



(most common / clockwise handle rotation)

* right hand Thread



* pitch diameter = effective diameter = the diameter at which the thread tooth and space are equal

$$Ed = T + 2x$$

$$T = D_c + (R_{th}(\text{wire}) - R_c(\text{wire}))$$

$$2x = \frac{p}{2}\cot\theta - d(\operatorname{cosec}\theta - 1)$$

d → wire diameter

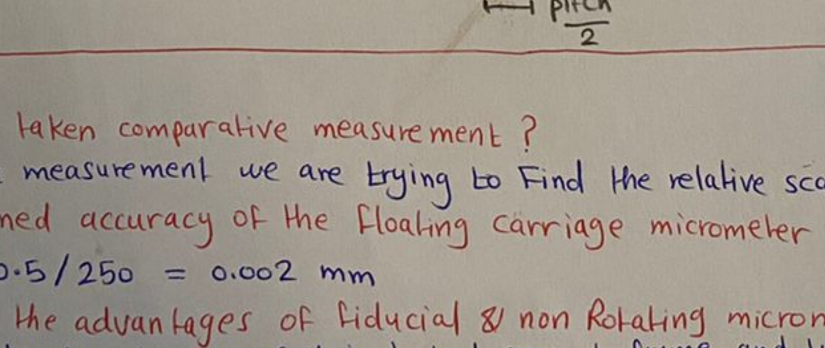
* major diameter (can be measured by micrometer, caliper or steel rule)
(it is good to measure the major diameter over the least used section of the screw)

$$\text{major } D_{th} = D_c + (R_{th} - R_c)$$

* minor diameter = the diameter that just touches the root of an internal thread

$$\text{minor } D_{th} = D_c + (R_{th}(\text{prism}) - R_c(\text{prism}))$$

* The crest of the thread = prominent part of the thread, whether internal or external
* The Root = the bottom of the groove between the two flanking surfaces whether internal or external
* The flanks of the thread = the straight sides that connect the crest and root
* The angle of the thread = angle between the flanks, measured in an axial plane section



Discussion :

Q1: why we are taken comparative measurement ?
In comparative measurement we are trying to find the relative scale of any part of the fig[ure]

Q2: The designed accuracy of the floating carriage micrometer ?
accuracy = 0.5/250 = 0.002 mm

Q3: what are the advantages of fiducial & non rotating micrometer spindle ?
- They are very durable because of their baked enamel frame and tungsten carbide faces
- They are very long-lasting and unlikely to need replacing or repairing

Experiment 5: Autocollimator

Autocollimator: optimal instrument used to measure small angles with very high sensitivity
↳ the applications are: ① precision alignment ② detection of angular movement
③ verification of angle standards ④ angle monitoring over long periods

⇒ Theory

- The autocollimator has it's own target which is projected by collimated light beams on a remotely placed surface and the reflected target image is observed in the ocular of the instrument
- The autocollimator is stationed at the end of the bed with rigid support base. The movement of the reflector along the bed will the cause the reflected image of the target to deflect according to the angular error of the bed
- The autocollimator is a flat mirror mounted in short tube made to fit a newtonian telescope focuser, and set accurately perpendicular to the tube's axis. Centered in it is a small peephole or pupil that you Look through

⇒ principles of operation of autocollimator

- The Autocollimator projects a beam of collimated parallel Light. An external reflector reflects all or part of the beam back into the instrument where the beam is focused and detected by a photo detector
- The Autocollimator measures the deviation between the emitted beam and the reflected beam. Because the autocollimator uses Light to measure angles, it never comes into contact with the test surface.

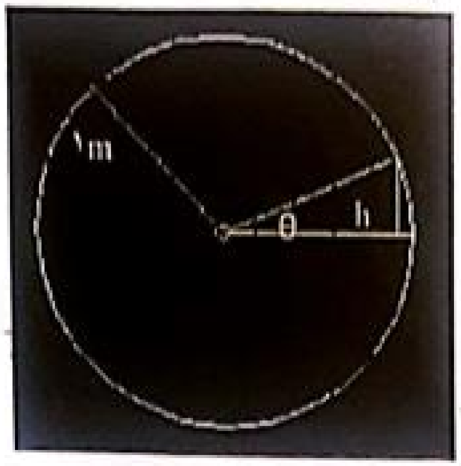
⇒ Visual Autocollimators

rely on the operator's eye to act as the photo detector. The operator views the reflected pinhole images through an eyepiece. because the human eye = photo detector, resolution will vary among operators. People can resolve from 3 to 5 arc-seconds.

⇒ Digital Autocollimators

they use an electronic photo detector to detect the reflector beam. The detector sends a signal to a controller with digitizes and processes the signal using proprietary DSP-based electronics. The processing creates a calibrated angular output. The angular data is retrieved using a digital LCD display. applications are:
① calibrating rotary tables ② checking angle standards ③ long term angular monitoring
④ Measurements of flatness & straightness ⑤ provide angular feedback in servo systems

⇒⇒ because the human eye is able to discern multiple surfaces simultaneously. This means that visual autocollimator are suitable for measuring multiple surfaces and This makes them ideal alignment instruments in applications Like aligning laser rod ends or checking parallelism among optics



$\tan\theta = h/$ radius

$\theta = 1$ sec of arc

$h = \tan 1$ sec x Radius

$h = 4.848 \times 10^{-6}$ meter

$h = 5$ micrometer / meter approximately

$h = 0.5$ micrometer / 10^{-3} mm

$$\tan(\theta) = \frac{h}{l}$$

Assume $\theta = 1\sec$

$\tan(\theta) \approx \theta$ for small values

$$1\sec = \left(\frac{1}{60\times 60}\right)\frac{\pi}{180} = 4.8\times 10^{-6}\,rad$$

$$h = 4.8\times 10^{-6}\,m$$

i.e. each 1 sec indicates a vertical distance of approximately 0.5 micron "since L = 0.1m".

ex:

For $\theta = 3°$ find the corresponding vertical distance, for L = 0.1m.

$$h = 3\times 60\times 60\times 4.8\times 10^{-7} = 5.18\times 10^{-3}\,m$$

$\theta = 1$ sec

$\tan\theta = \frac{h}{L}$

$1\sec = \frac{1}{60\times 60}\times\frac{\pi}{180}$

$1\sec = \frac{1}{60\times 60}\cdot\frac{\pi}{180}$

$\theta = 1$ sec of arc

$\tan\theta = \frac{h}{L}$

$1\sec = \frac{1}{60\times 60}\cdot\frac{\pi}{180}$

$\tan\theta =$

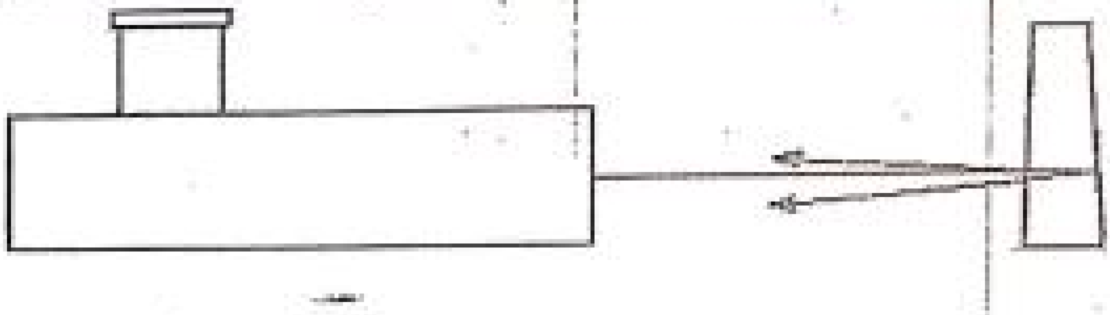
$h = \frac{\Delta y}{L} = \frac{1}{60\times 60}\times\frac{\pi}{180}$

$h = \Delta y$

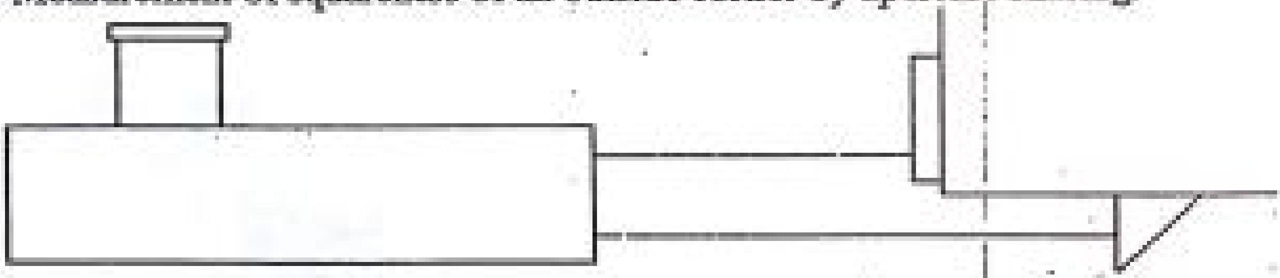
$\tan\theta = \frac{h}{L}$

Visual Autocollimator Sample Applications

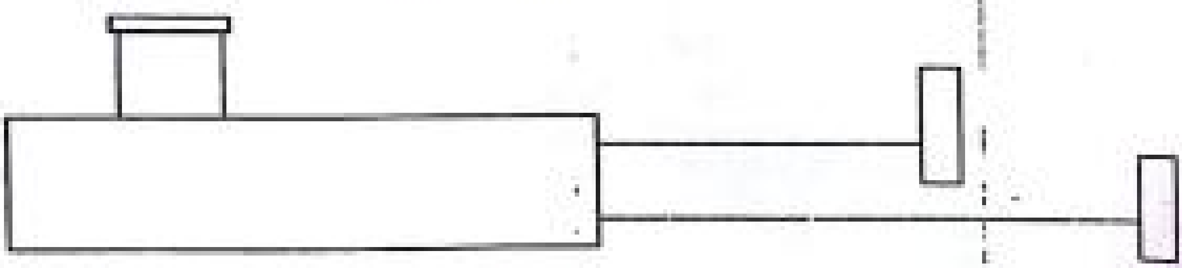
1-Measurement of non-parallelism in windows, laser rod ends,



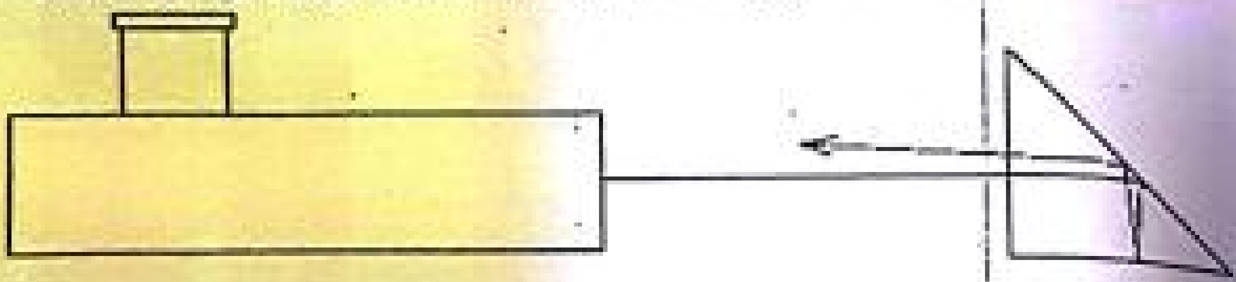
2-Measurement of squareness of an outside corner by aperture sharing.



3- Angle comparisons by aperture sharing.



4- Checking right angle prisms for angular and pyramid errors



PROCEDURE

1. Clean the surface plate or table.

2. Position the auto-collimator in line with the reflector. Switch on the lamp in the autocollimator, the alignment between the auto-collimator and reflector should be checked at both extremes of the operational distance to make certain that the target graticule is contained within the eyepiece field.

3. Fix a guide strip to control the horizontal displacement of the reflector and minimise the movement of the target graticule.

4. Mark off the positions along the surface plate equal to the pitch positions on the reflector base (in this case 100 mm). Column 1 should indicate this position.

5. At the initial position takes the reading and tabulates (column 2)
6. Move the carriage (reflector) to the next position and again tabulate the reading.

7. This method is to continue until the final outward position is recorded.

<u>To improve on the accuracy and ensure no errors have been introduced</u>, readings should also be taken on the inward run. If this exercise is followed then the average of the two readings is to be shown in column 2.

Experiment 6: RTD & Thermocouple & Thermistor.

1 → RTD = Resistance Temperature Detectors

electrical resistors that change resistance as temperature changes, with all types of RTD the resistance increases as temperature increases, this is referred to as positive temperature coefficient PTC

(*) RTD's are manufactured using different materials as the sensing element

① the most common is platinum RTD → this is used for many resons: high temperature rating / very stable / very repeatable

② Nickel RTD ③ copper RTD ④ Nickel-iron RTD

→ **wire-wound RTD construction**

created by winding a thin wire into a coil

→ **thin-film RTD construction (most common)**

- consists of a very thin layer of metal laid out on plastic or ceramic substrate
- these are cheaper & more widely available [because] they can achieve higher nominal
- resistances with less platinum
- To protect RTD, a metal sheath encloses the RTD element and lead wires connected to it

→ **RTD's are popular** → because of their stability

- they exhibit the most Linear signal with respect to temperature
- they are generally most expensive because of the careful construction and the use of platinum
- they are charcterized by: slow response time / low sensitivity / require current excitation they can be prone to self-heating

→ **RTD nominal resistance at 0°c / Resistance values include 100 & 1000 Ω**

2 → Thermistor

they are thermally sensitive semiconductors whose resistance vary with temperature. they are manufactured from metal oxide semiconductor material encapsulated in a glass or epoxy bead. Thermistors have much higher nominal Resistance than RTD's (from 2,000 to 10,000 Ω) and can be used for lower currents

(*) nominal resistance varies proportionally with temperature according to linearized approximation. They have either negative temperature coeff. (NCT) or positive (PCT)

NCT → has a resistance decreases with increasing temperature

PCT → has a resistance increases with increasing temperature

(*) Thermistors have very high sensitivity (~200 Ω/°c) that why they are extremely responsive to changes in temperature.

(*) Though they exhibit fast response rate but they are limited for use up to the 300°c temp. range. This along with their high nominal Resistance, helps to provide precise measurements in lower-temp. applications

(*) In TMTOOl we use NTC thermistor has temp. range (13-85 c°).

3- Thermocouple

Introduction:

Thermocouple (TC) is created whenever two dissimilar metals touch and the contact point produces a small open-circuit voltage as a function of temperature. This thermoelectric voltage is known as the Seebeck voltage, named after Thomas Seebeck, who discovered it in 1821.

The TC has been the popular choice over the years for a variety of reasons. Thermocouples are relatively inexpensive and can be produced in a variety of sizes and shapes. They can be of rugged construction, can cover a wide temperature range. However, TCs produce a very small microvolt output per degree change in temperature that is very sensitive to environmental influences.

As Mentioned above any two dissimilar metals may produce a TC, However, there are some standard thermocouples which have calibration tables and assigned letter-designations which are recognized worldwide, Such as, J-type (Iron / Constantan), K-type (Chromel / Alumel), E-type (Chromel / Constantan), N-type (Nicrosil / Nisil), B-type (Platinum / Rhodium), R-type (Platinum / Rhodium) and S-type (Platinum / Rhodium). In order to select the suitable TC for an application, sensitivity and temperature range should be taken into consideration, because each one of these thermocouples has different temperature range and sensitivity.

In the experiment two J type thermocouples are used. The first one is used for the experiments, and the other one is used with temperature controller to control the temperature of the hot plate.

To measure a thermocouple Seebeck voltage, you cannot simply connect the thermocouple to a voltmeter or other measurement system, because connecting the thermocouple wires to the measurement system creates additional thermoelectric circuits.

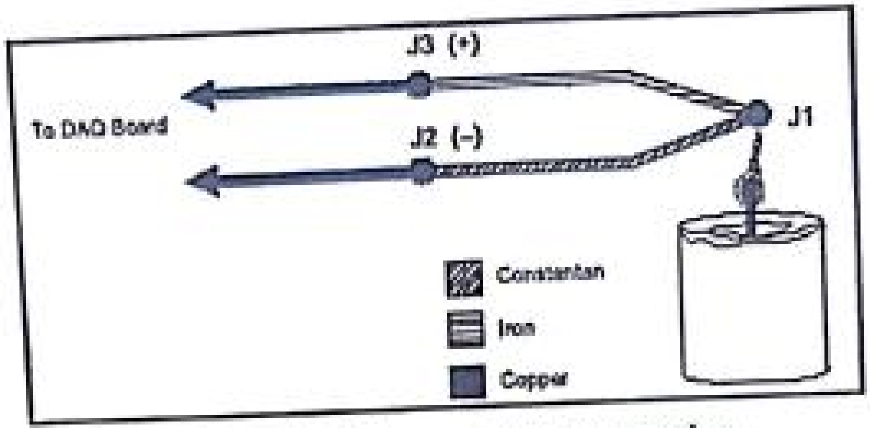


Figure (1): Thermocouple connection

Consider the circuit illustrated in Figure 1, in which a J-type thermocouple is in a candle flame that has a temperature you want to measure. The two thermocouple wires are connected to the copper leads of the measurement device. Notice that the circuit contains three dissimilar metal junctions J1, J2, and J3. J1, the thermocouple junction, generates a Seebeck voltage proportional to the temperature of the candle flame. J2 and J3 each have their own Seebeck coefficient and generate their own thermoelectric voltage proportional to the temperature at the measurement device terminals. To determine the voltage contribution from J1, you need to know the temperatures of junctions J2 and J3 as well as the voltage-to-temperature relationships for these junctions. You can then subtract the contributions of the parasitic junctions at J2 and J3 from the measured voltage at junction J1.

Thermocouples require some form of temperature reference to compensate for these unwanted parasitic "cold" junctions. The most common method is to measure the temperature at the reference junction with a direct-reading temperature sensor and subtract the parasitic junction voltage contributions. This process is called **cold-junction compensation**. You can simplify computing cold-junction compensation by taking advantage of some thermocouple characteristics.

By using the **Thermocouple Law of Intermediate Metals** and making some simple assumptions, you can see that the voltage a data acquisition system measures depends only on the thermocouple type, the thermocouple voltage, and the cold-junction temperature. The measured voltage is in fact independent of the composition of the measurement leads and the cold junctions, J2 and J3.

According to the Thermocouple Law of Intermediate Metals, illustrated in Figure 2, inserting any type of wire into a thermocouple circuit has no effect on the output as long as both ends of that wire are the same temperature, or isothermal.

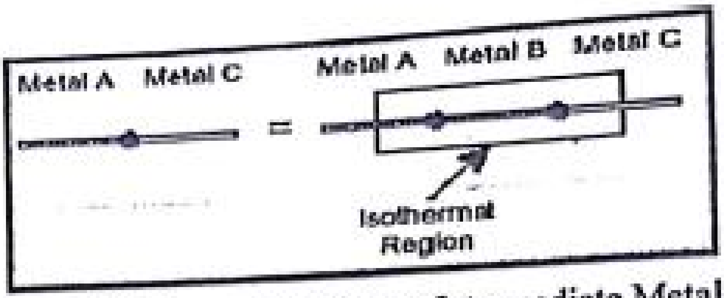


Figure (2): Thermocouple Law Intermediate Metals.

Consider the circuit in Figure 3. This circuit is similar to the previously described circuit in Figure 1, but a short length of constantan wire has been inserted just before junction J3 and the junctions are assumed to be held at identical temperatures. Assuming that junctions J3 and J4 are the same temperature, the Thermocouple Law of Intermediate Metals indicates that the circuit in Figure 3 is electrically equivalent to the circuit in Figure 1. Consequently, any result taken from the circuit in Figure 3 also applies to the circuit illustrated in Figure 1.

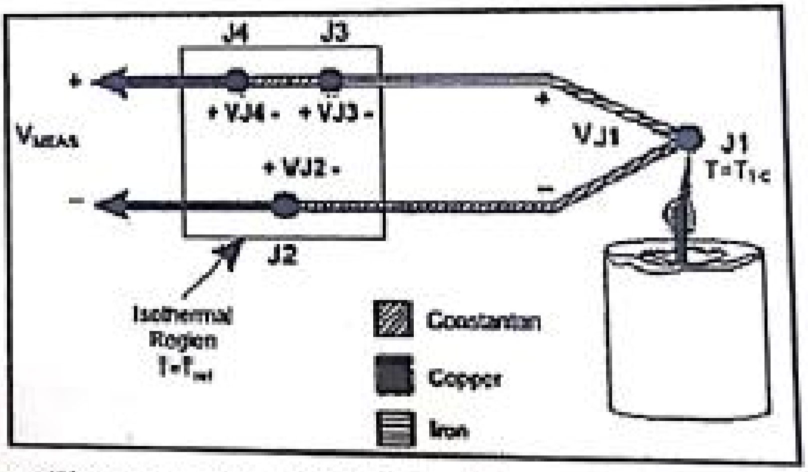


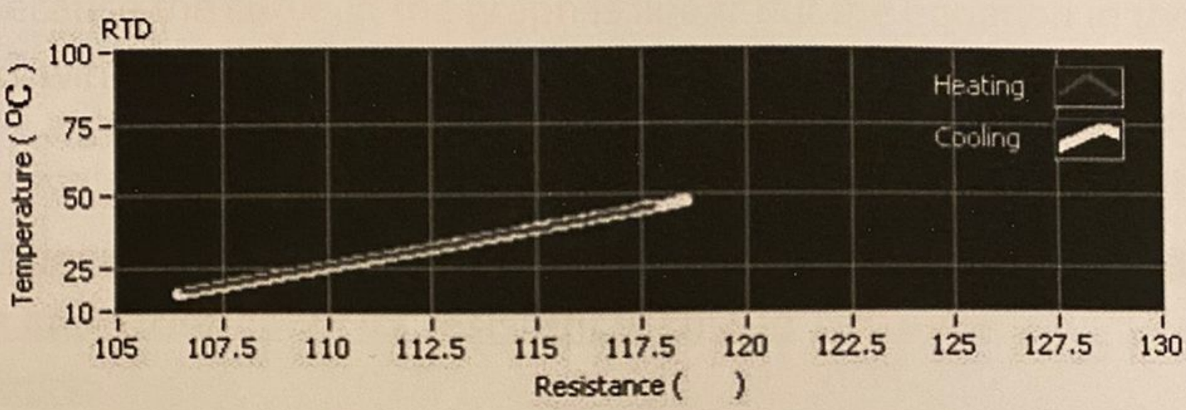
Figure (3): Intermediate Materials effect In Isothermal region.

In Figure 3, junctions J2 and J4 are the same type (copper-constantan); because both are in the isothermal region, J2 and J4 are also the same temperature. Because of the direction of the current through the circuit, J4 contributes a positive Seebeck voltage, and J2 contributes an equal but opposite negative voltage. Therefore, the effects of the junctions cancel each other, and the total contribution to the measured voltage is zero. Junctions J1 and J3 are both iron-constantan junctions, but may be at different temperatures because they do not share an isothermal region. Being at different temperatures, junctions J1, J3 both produce a Seebeck voltage, but with different magnitudes. To compensate for the cold junction J3, its temperature is measured and the contributed voltage is subtracted out of the thermocouple measurement.

questions

The Resistance Temperature Detector (RTD)

Characteristics



7. Compare the read temperature with the temperature of the glass thermometer. Is it the same? Why?

No, because thermometers have different fluids and different expansion rate of temperature.

12.Is the cooling curve the same as the heating curve? Why?

Yes, they are the same, heating curves show how the temperature changes as the plate is heated up and cooling curves are the opposite (when the plate is cooled down).

13.Notice the Temperature vs. Resistance curve and answer the following questions:

14.1 Is the curve Linear? Yes, it is linear.

4.2 Does the RTD equation in "Theory" window describe the curve on the Temperature-Resistance graph? If your answer is "No", what is the difference and why?

No, because the curve in the graph is linear but the equation in the theory window has a square root (not linear).

15. Choose one of the readings taken before from the readings table and write down its resistance (Ω) and Temperature (°C) readings:

15.1 Current Resistance (Ω): 106.521829

15.2 Current temperature (°C): 16.722639

15.3 Apply the current resistance in the RTD equation

$$T = \frac{R_{.} - R}{-0.5(R_{.}A + \sqrt{R_{.}^{2}A^{2} - 4R_{.}B(R_{.} - R)})}$$

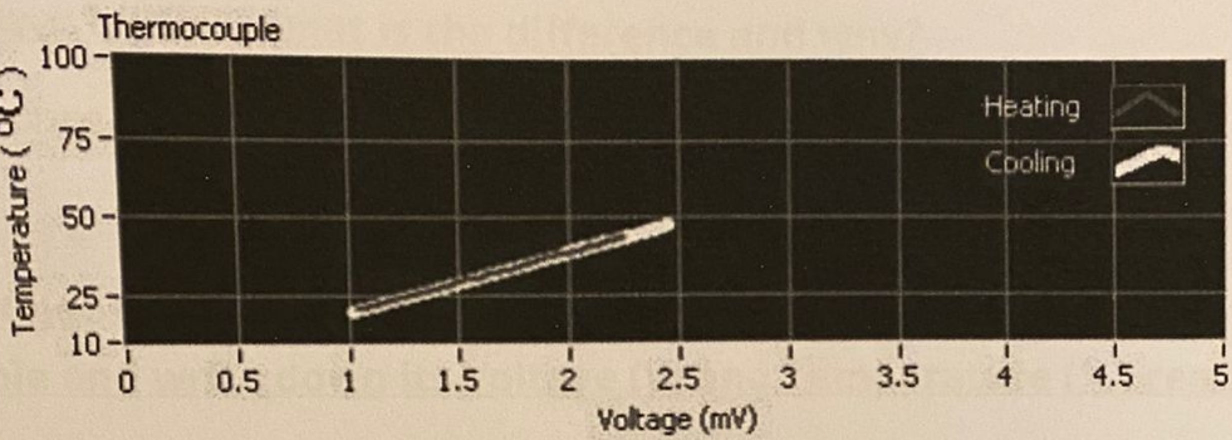
15.4 Write down the calculated temperature (°C): 16.72987344

15.5 Compare the calculated temperature with the current temperature. Both values are very close to each other.

Conclusions:

- RTD (Resistance Temperature Detector) is a temperature sensitive resistor.
- Stable linear change in resistance with temperature change
- It is a positive temperature coefficient device, which means that the resistance increases as temperature increases.

Thermocouple Characteristics



14. Compare the read temperature with the temperature of the glass thermometer. Is it the same temperature? Why? No, since a glass thermometer measures temperature difference by measuring the difference in voltage between metals, whereas a thermocouple measures temperature difference by measuring the difference in voltage between metals.

19.Is the cooling curve the same as the heating curve? Why?

Yes, the positive Temperature coefficient PTC. The heating curve is in an increasing manner while the cooling curve is in the decreasing manner. Same slop magnitude but different sign due to direction.

22.Notice the temperature vs, voltage curve and answer the following questions:

22.1 Is the curve linear? Yes, it is linear.

22.2Does the thermocouple equation in the "Theory" window describes the curve on the Temperature vs. Voltage graph? If your answer is "No", what is the difference and why?

No, since theory describes non-linear relations.

23. Choose one of the readings taken before from the Readings Table and write down its Voltage (V) and Temperature (°C) readings:

23.1 Current Voltage (V): 1.421824

23.2 Current temperature (°C): 27.789175

23.3 Apply the current voltage in the thermocouple equation below

$$T = V(1.978425 * 10^{-2}) + V^2(-2.001204 * 10^{-7}) + V^3(1.036969 * 10^{-11}) + V^4(-2.549687 * 10^{-16}) + V^5(3.585153 * 10^{-21}) + V^6(-5.344285 * 10^{-26}) + V^7(5.099890 * 10^{-31})$$

Where: T : Calculated temperature in (°C)
V : Thermocouple voltage in microvolt ($V*10^6$)

23.4 Write down the calculated temperature (°C): 27.79012

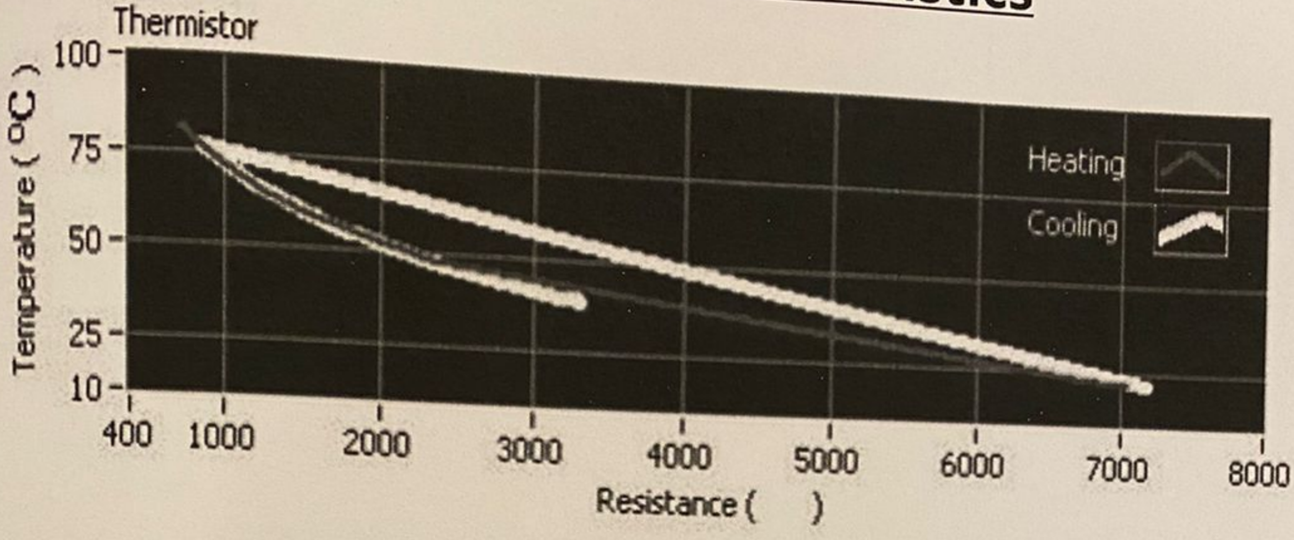
23.5 Compare the calculated temperature with the current temperature:

The calculated temperature is almost equal to the current T, there is a slightly difference because the dealing with the digits and hand solution with small measuring error (1.0402*10-3)

Conclusions:

- Thermocouples measures the open circuit voltage at the contact point of two dissimilar metals.
- Thermocouples can cover a wide temperature range.
- Thermocouples can be used for applications (above 1000 C),
- Thermocouples are relatively inexpensive and can be produced in a variety of sizes and shapes.

Thermistor Characteristics



7.Compare the read temperature with the temperature of the glass thermometer. Is it the same temperature? Why?

No, it is not the same, that's because Thermistors are thermally sensitive semiconductors whose resistance varies with temperature.

12.Is the cooling curve the same as the heating curve? Why?

Yes, while the fans are on and the heater is off, heating curve shows how temperature as the substance heated up, cooling curve are the opposite.

13.Notice the Temperature vs. Resistance curve and answer the following questions:

14.1 Is the curve linear? No, it is not linear.

14.2Does the Thermistor equation in the "Theory" window describe the curve on the Temperature-Resistance graph? If your answer is "No", what is the difference and why?

Yes, in both cases while decreasing in resistance the temperature is increased.

Choose one of the readings taken before from the Readings Table and write down its Resistance (Ω) and Temperature (Co) readings:

15.1Current Resistance (Ω): 7056.629303 Ω

15.2 Current temperature (°C): 21.341291 °C

15.3 Apply the current resistance in the thermistor equation

$$T = \frac{1}{a + b(ln\,R) + c(ln\,R)^3}$$

15.4Write down the calculated temperature (°C): 294.5 K = 21.34 °C

15.5 Compare the calculated temperature with the current temperature: We noticed that the calculated temperature is very close and kind of equal to the current temperature.

Conclusions:

- Thermistors, are thermally sensitive semiconductors whose resistance varies with temperature.
- Thermistors have either a negative temperature coefficient (NTC) or a positive temperature coefficient (PTC). The first, more common, has a resistance that decreases with increasing temperature while the latter exhibits increased resistance with increasing temperature.
- Thermistors typically have a very high sensitivity (˜ 200 Ω/°C), making them extremely responsive to changes in temperature. Though they exhibit a fast response rate, thermistors are limited for use up to the 300 °C temperature range.

Thermometers Comparison

13. Are the cooling curves of the thermometers the same as the heating curves? Why?

Heating and cooling curves for thermocouples and RTDs are the same, while thermistor curves are different.

14. Notice the Temperature – Voltage (or Resistance) curves and the Temperature – Time (on the trends tab) and answer the following questions:

14.1 Which one of the thermometers has the fastest response time?

Thermistor

14.2 Which one of the thermometers has the slowest response time?

RTD

15. Depending on this and the previous experiments assign the suitable thermometer for the following applications and explain why:

15.1 An application with a wide temperature range (above 1000°C)

Thermocouple, because thermocouples can cover a wide temperature range and applications above 1000°C.

15.2 An application that needs a good response time (temperature range is up to 500°C).

Thermocouple or thermistor because both have a good fast response time.

15.3 An application that needs accurate readings and fast response time (temperature range is up to 80°C)

Thermistor because it is the most sensitive and the fastest.

15.4 An application that needs a repetitive sensor (temperature range is up to 500°C)

RTD.

15.5 An application that has electromagnetic fields (temperature range is up to 500°C)

Thermocouple they perform good in most environments.

15.6 An application in which the wires length of the sensor does not affect the temperature readings (temperature range is up to 500°C)

RTD.

15.7 An application in which the wires length of the sensor does not affect the temperature readings (temperature range is up to 50°C)

Thermistor.

Experiment 7 : strain gauge

Introduction

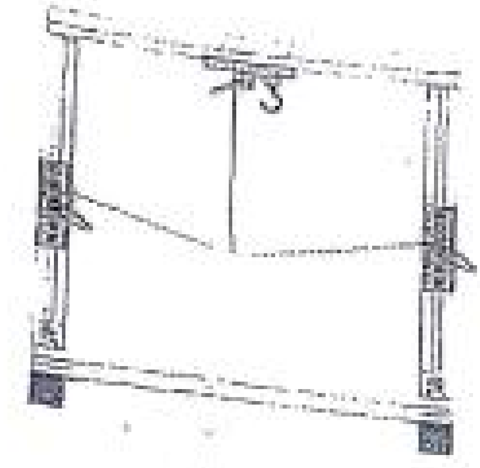
Strain gauges permit simple and reliable determination of stress and strain distribution at real components under load. The strain-gauge technique is thus an indispensable part of experimental stress analysis. Widespread use is also made of strain gauges in sensor construction (scales, dynamometers and pressure gauges, torque meters).

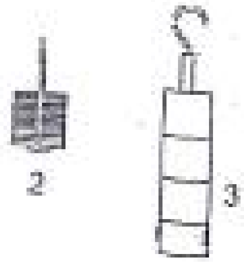
All **test objects** are provided with a full-bridge circuit and are ready wired. A Perspex cover protects the element whilst giving a clear view.
The test objects are inserted in a frame and loaded with weights.

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.

2 Unit description

2.1 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 0.5 N for bending experiments

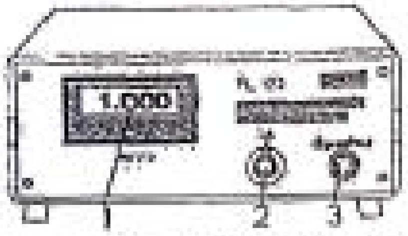
2.2 Test objects

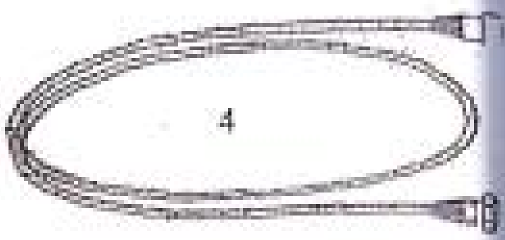
2.2.1 Bending beam

The test object used for bending experiments is a clamped steel cantilever beam (4).
- Length L: 385 mm
- Cross section Area:
  h=4.75 mm
  b=19.75 mm
- Modulus of elasticity E: 210000 N/mm2

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

2.3 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).

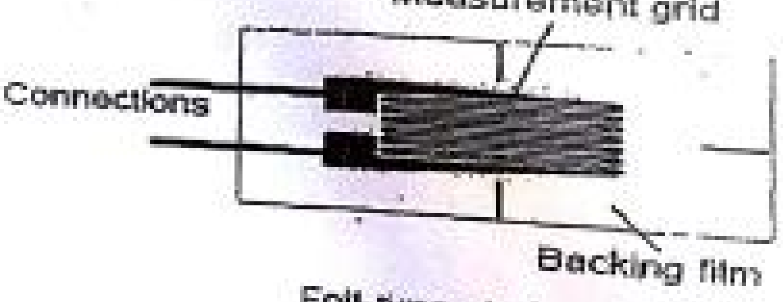
- Range: ± 2.000 mV/V
- Resolution: 1 μV/V.
- Balancing range: ± 1.0 mV/V.
- Nominal strain-gauge resistance: 350 Ω
- Strain-gauge feed voltage : 10V
- Power supply: 230V / 50Hz

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.

3 Experiments

3.1 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.



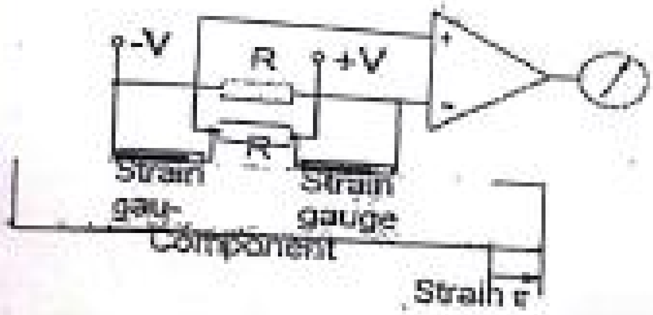
Foil-type strain gauge
(greatly enlarged)

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. 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**

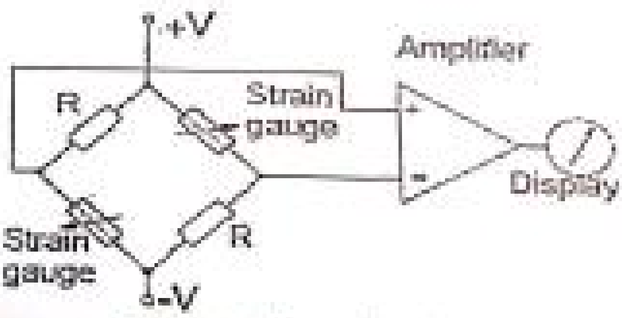
$$k = \frac{\Delta R / R_0}{\varepsilon}$$

ε : strain
R_0 : resistance at zero point (no force) Ω
ΔR : change in resistance after applying force Ω

Strain gauges with a large k-factor are more sensitive than those with a small one. The constantan strain gauges used have a **k-factor of 2.05**. 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).



Configuration of half bridge on component



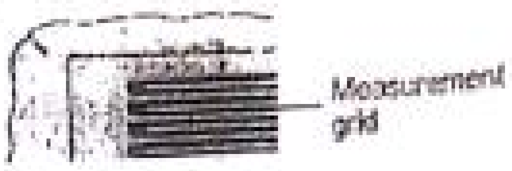
Halve-bridge circuit

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.

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.

dhesive



Design of strain gauge

3.3 Bending experiment

3.3.1 Fundamentals

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

$$\sigma = \frac{M_b}{W_y}$$

Bending moment calculated for cantilever beam

$$M_b = -F \cdot L$$

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

$$W_y = \frac{b\,h^2}{6}$$

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 U_A of the measuring bridge is referenced to the feed voltage U_E. The sensitivity k of the strain gauge enables the strain ε to be calculated for the full bridge as follows

$$\varepsilon = \frac{1}{k} \cdot \frac{U_A}{U_E}$$

According to Hooke's law the stress being sought is obtained with the modulus of elasticity E (Modulus of elasticity for steel: 210000 N/mm2)

$$\sigma = \varepsilon \cdot E$$

Example:

The stress is now to be determined for a load of 6.5 N where the reading was $-0.227.10^{-3}$. The following results for the strain

$$\varepsilon = \frac{1}{k}\left(\frac{U_A}{U_E}\right)$$

$$= \frac{1}{2.05}\cdot(-0.227\cdot10^{-3})$$

$$= -0.0001107.$$

The modulus of elasticity for steel of 210000 N/mm2 gives the following stress

$$\sigma = \varepsilon \cdot E$$

$$= -0.0001107 \cdot 210000 = -23.25\ N/mm^2.$$

The measured stress is to be compared to the theoretical result in the following. The section modulus for the rectangular cross section is $W_y = 74.26\ mm^3$.

The calculation produces the following stress

$$\sigma = \frac{Mb}{Wy}$$

$$= -6.5 \cdot 250/74.26 = -21.88 N/mm^2.$$