EXPERIMENTAL TECHNIQUES STRESS ANALYSIS

DEPARTMENT OF MECHANICAL ENGINEERING

FACULTY OF ENGINEERING

L-UNIVERSITÀ TA' MALTA

STUDENTS’ ACTIVITY

This lab work will be carried out as a group activity. Students will be divided into groups by their supervisor and then it is up to the students to organise themselves. It is always essential to have a team leader !

The students have to at least read the course notes on Mechanics of Materials **and augment it by means of further literature search**. Students need only refer to mechanics of materials textbooks and data provided with the equipment.

The students need to perform the test on one machine / experimental setup in the mechanics lab situated on ground level on the west side of the Faculty of Engineering building. Usually there are set three hour laboratory periods during which students can meet with and get help from their supervisor. If students wish to perform further investigation they can arrange with the lab officer in charge in order to use the lab and the equipment outwith these set periods.

Each team is required to write one report (not more than 10 pages long) and present their work in front of their colleagues and supervisor in the form of a formal presentation (see attached practical tips on presentations). Each presentation must be of 10 minutes duration with 5 minutes left for questions. In the report (see attached notes) and presentation, students need to highlight how the test was performed, what readings were taken, difficulties met, etc. It is essential that each statement that is presented is backed up by an explanation.

It is of paramount importance that students prepare beforehand for the lab session in the sense that they know what measurements they need to take and how to carry out the test. After the test is completed students need to plot the required curves and perform the necessary calculations to check whether there is some gross mistake in their testing. If so, the test or parts of the test have to be repeated.

Students will be given a mark as a whole team so it is important that everybody gives an input in the work.

Students are encouraged to try to limit questions asked to the supervisor and lab officer to a minimum. The idea of the exercise is to leave the students to carry out their own investigations and obtain their own conclusions and results. Experience has shown us that in this way the lab session is more interesting and students learn more. The aim of the presentations is so that students learn from each others’ work through the discussion after the presentation. So enjoy !

Looking forward to meet you in the lab !

SOME NOTES ON LAB WORK

The purposes of experimentation as a subject in the curriculum are many, but perhaps the most important ones are to provide opportunities for the student to

1. Verify certain theories
2. Become familiar with methods of measurements
3. Organise his/her own work and carry it through systematically and carefully
4. Help to organise the work of a team
5. Analyse data, assess their reliability and draw conclusions from them

The student is advised to enter every detail of his work as he proceeds into a notebook. The student needs to acquire this habit which he will find to be very useful in his career. The student should not try to seek the help of supervisory staff during a lab session except in cases of emergency or difficulties which cannot be resolved otherwise.

<u>Reporting the work:</u>

Structure of the report:

A formal report will usually consist of sections falling under some or all of the following headings:

- Front page which includes the heading, the student names, academic year, group number
- Title
- Object of the experiment
- Table of contents
- Introduction
- Notation used
- Theory
- Procedure and apparatus used (drawing or sketch)
- Results
- Discussion
- Conclusions or recommendations
- References
- Figures
- Appendices

Plotting graphs:

1. Always give a title and number to each graph
2. Include the scales and units of the variables
3. Mark the points clearly - +, *, ¤, O, ڤ, ●, ▲, ▼
4. Include a legend
5. If you plot cirves on the same axes distinguish between them by using different kinds of ruling (colour, continuous, dotted, dash dot, etc)

Finally be sure to present a well structured report which shows that you understood your work.

PRACTICAL TIPS FOR PRESENTATIONS

Before giving a presentation it is always helpful to ask some questions to yourself :

1. What is the purpose of your presentation ?
2. What will your audience want to know ?

In an oral presentation it is always a good idea to:

1. Introduce yourself and your group
2. Highlight your main points i.e. give a brief overview of your presentation

Other practical tips :

1. Keep slide special effects to a minimum – these distract the attention of your audience.
2. Use only two colours or maximum three in your slides.
3. Use a large enough font so that words can be read by someone sitting at the back seat.
4. While presenting try not to read too much from your slides which must be concise and to the point. On the other hand slides must make sense if your audience tries to read some of them.
5. Do not flip forward or backward to search for a figure – it is better to repeat it and put it in place.
6. Do not show complicated figures but try to simplify them as much as possible – remember that in a presentation usually you only have 15 minutes to deliver what you want to deliver.
7. When using a projector or slide projector try to stand by the screen and point with a laser pointer or with some other pointer such as a slender rod.
8. Remember to breathe well during your presentation.
9. Speak slowly and distinctly.
10. Avoid too much slang.
11. Dress should be slightly smarter than your audience' – shoes clean and shiny, conservative business office dress, well groomed hair.
12. Presentations require practice, practice and more practice especially if it is to be delivered in the English language.
13. During question time be sure to understand the question well.
14. Do not be shy to admit on drawbacks of your work or whatever you presented.
15. Always show respect to your audience and especially build a good rapport with the session chair.
16. Finally enjoy presenting your work and making people interested. Keep in mind that your audience want you to succeed so that they gain from your presentation.

RESISTANCE STRAIN GAUGES

Introduction

Strain gauges consist of a short length of fine wire of known resistance cemented to a non-conductive backing. The setup is then glued to the surface of the material being tested. The resistance of the wire changes by small amounts as the wire is stretched, so that the gauge indicates a change in resistance which is measurable by means of a wheatstone bridge circuit and amplifier. The size of strain gauges can be as small as 6mm and they are therefore extremely useful for measuring local extensional strains. Sometimes strain gauges are clustered together to form a strain rosette. Normally these consist of 3 strain gauges placed at convenient angles of 45^o or 60^o to each other and fixed to a single backing. Three strain measurements at a point give sufficient information to determine the complete state of plane strain at a point.

It is essential that the bonding of the strain gauge to the area being tested be done carefully so that intimate contact between the material and the gauge is assumed. Usually proprietary adhesive and bonding instructions are supplied with the strain gauges to be used. Any strain in the material is then directly transmitted to the gauge, which therefore increases or decreases in length. The wire's cross-sectional area is also slightly altered. This results in a corresponding increase or decrease in its electrical resistance. The resistance of the wire is given by the formula $R = \frac{\rho l}{A}$ where l is the length of the wire, A is the cross sectional area and ρ is the resistivity. The resistance change divided by the original resistance is found to be directly proportional to the change in strain of the specimen i.e. $\delta\varepsilon = \frac{1}{k}\frac{\delta R_o}{R_o}$ where k is the gauge factor given by the manufacturer and R_o is the original gauge resistance. For most materials the gauge factor is approximately equal to 2. Although strain gauges are intended to measure strains in one direction only, the small lengths of the conductor in the direction at right angles to the axis of the gauge impart some degree of sensitivity to transverse strain. This effect is usually small enough to be neglected in work of normal accuracy.

Standard gauge resistances of metal-foil commercially available strain gauges are 120Ω and 350Ω. Commercially available gauge lengths vary from 0.2mm to 100mm to meet a variety of strain gauge applications.

To calibrate the strain gauge it should glued to a calibration beam strained in pure bending. The surface strain can then be calculated from the beam dimensions, material properties and the measured deflections. Simultaneous measurement of change of resistance permits determination of the gauge factor. This calibration procedure is normally done by the manufacturer.

Strain gauge installation, bonding and soldering techniques

This is normally data provided by the strain gage manufacturer. Refer to the 'Student manual for strain gage technology' available in the Mechanics lab.

Gage selection procedures and temperature effects

Gage selection mostly depends on the application and temperature changes occurring during the testing period. Practically there are two main methods to be used to eliminate the change in resistance due to temperature fluctuations. One method is to select self-temperature compensated strain gages. The second method is to compensate for the effects of the temperature change in the wheatstone bridge circuit used to measure gage output. For further details refer to the 'Student manual for strain gage technology' available in the Mechanics lab.

Strain gage circuitry - The Wheatstone bridge

The wheatstone bridge is a basic circuit employed to measure extremely small resistance changes in a strain gage when it is subjected to a strain.

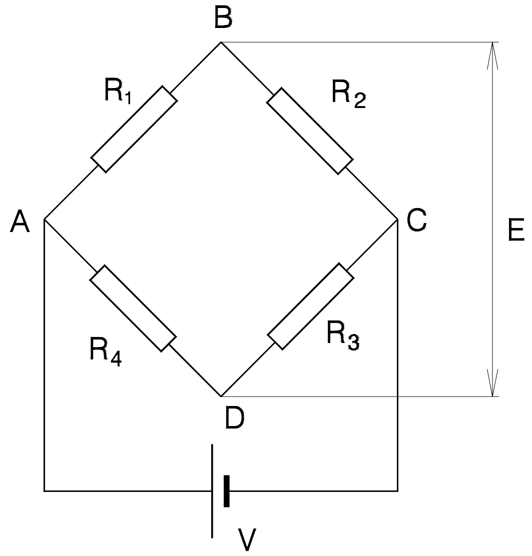

Figure 1 – Constant voltage wheatstone bridge

Let us denote the voltage drop across R_1 and R_4 by V_{ab} and V_{ad} respectively. It can be shown that

$V_{ab} = \frac{R_1}{R_1 + R_2} V$ and $V_{ad} = \frac{R_4}{R_3 + R_4} V$ where V is the supply voltage.

The voltage output of the bridge is given by $E = V_{ab} - V_{ad} = \frac{R_1 R_3 - R_2 R_4}{(R_1 + R_2)(R_3 + R_4)} V$

We say that the bridge is balanced when E is zero i.e. when $R_1R_3 = R_2R_4$ **(1)**

Any change in the resistance in one arm of the bridge can be balanced by adjusting the resistances in the other arms of the bridge. Consider an initially balanced bridge. If the original resistances R_1, R_3, R_2, R_4 are slightly changed then the output voltage of the bridge is given by

$$\Delta E = \frac{(R_1 + \Delta R_1)(R_3 + \Delta R_3) - (R_2 + \Delta R_2)(R_4 + \Delta R_4)}{(R_1 + \Delta R_1 + R_2 + \Delta R_2)(R_3 + \Delta R_3 + R_4 + \Delta R_4)} V \qquad \textbf{(2)}$$

Using equation 1 and neglecting products of small quantities like $\Delta R_1.\Delta R_3$ and relatively smaller terms $R_1.\Delta R_3$ it can be shown that

$$\Delta E = \frac{R_1 R_2}{(R_1 + R_2)^2} \left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4} \right) V \qquad \textbf{(3)}$$

Note that the small quantity terms must be included when the strains being measured are greater than 5%. These terms will cause the wheatstone bridge to be non-linear.

The sensitivity of the wheatstone bridge S_w can be defined as $S_w = \frac{\Delta E}{\varepsilon}$ **(4)**

A fixed voltage is normally applied to the bridge so that the sensitivity depends on the number of active arms used, the gage factor k and the resistance ratio $\frac{R_2}{R_1}$. The input voltage can be increased in order to increase sensitivity. The upper limit for input voltage depends on the power dissipated by the strain gages used in the bridge. Once a particular gage type is selected, the gage factor cannot be varied to increase sensitivity. Sensitivity can then only be increased by changing the number of active arms (Quarter, half and full bridge arrangements) and the resistance ratio.

Quarter Bridge

The arrangement is called a quarter bridge when only one active strain gage is used as shown in Figure 2.

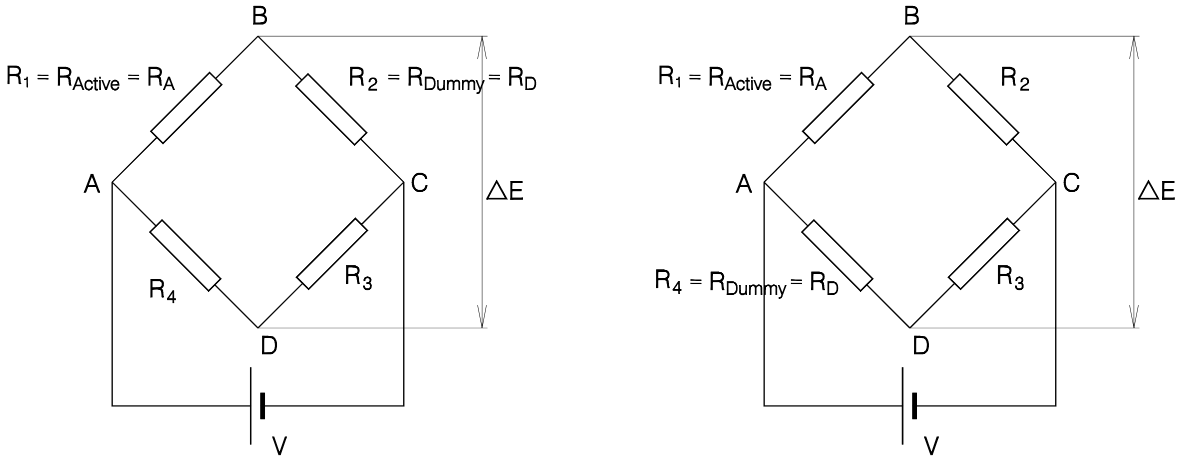

Figure 2 – Quarter bridge arrangements

The active gage is bonded to the component in the place where we need to measure strain. A dummy gage is included in the circuit to compensate for resistance change due to temperature changes. The dummy gage should not be bonded to a stressed part of the component but to an unstressed part that is close to the active gage. Both gages should be of the same type. Using equation 3 it is easily shown that changes in resistance due to temperature effects cancel out so that the bridge out of balance voltage is related only to the strain due to mechanical loads. If the bridge is initially balanced then the output voltage will be given by

$$\Delta E = \frac{R_1 R_2}{(R_1 + R_2)^2}\left(\frac{\Delta R_A}{R_A}\right)V = \frac{R_1 R_2}{(R_1 + R_2)^2}\varepsilon.k.V \qquad \textbf{(5)}$$

where R_1 and R_2 are given by the arrangement selected from Figure 2. Rearranging equation 5 we get

$$\varepsilon = \frac{(R_1 + R_2)^2}{R_1 R_2 .k.V}\Delta E \qquad \textbf{(6)}$$

It is only necessary to measure the out of balance voltage to obtain the strain when the bridge excitation voltage and gage factor are known.

For two and three wire circuits used in quarter bridge arrangements refer to the 'Student manual for strain gage technology – page 24' available in the Mechanics lab.

Half Bridge

The arrangement is called a half bridge when two active strain gages are used as shown in Figure 3.

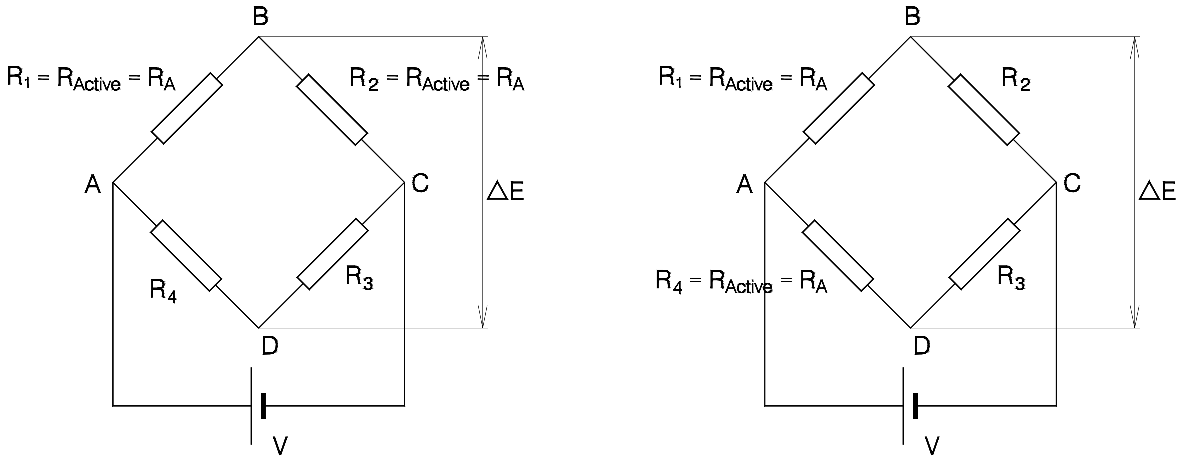

Figure 3 – Half bridge arrangements

Both gages are now active. This configuration has advantages for temperature compensation and higher bridge sensitivity over the quarter bridge so that small strain levels can be detected more accurately.

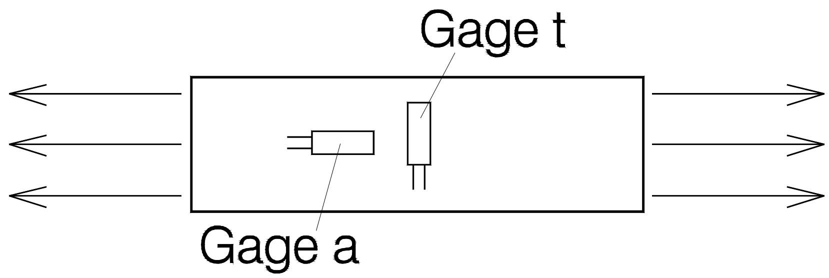

Figure 4 – Application for half bridge arrangement

Figure 4 shows an example of a half-bridge application – A rod is subjected to a tensile load. Gages *a* and *t* are mounted along the axial and transverse directions. The corresponding bridge connections (Figure 3 R.H.S.) are as such: gage *a* corresponds to gage R_1 while gage *b* corresponds to gage R_2. Then the output voltage is given by

$$\Delta E = \frac{R_1 R_2}{(R_1 + R_2)^2}\left(\frac{\Delta R_A}{R_A} - \frac{\Delta R_T}{R_T}\right)V = \frac{R_1 R_2}{(R_1 + R_2)^2}\left(\frac{\Delta R_A}{R_A} + \frac{\lambda.\Delta R_A}{R_A}\right)V = \frac{R_1 R_2}{(R_1 + R_2)^2}(1+\lambda).k.\varepsilon.V \quad \textbf{(7)}$$

where both gages are of the same make so that $R_A = R_T$.

If two pairs of gages are mounted in a diametrically symmetric direction, then employing a half-bridge circuit by connecting the corresponding gages in series we can automatically cancel the bending strains.

Full Bridge

In this arrangement four active gages are employed in the bridge. A full bridge is automatically temperature compensated when all four active gages (of the same type) are bonded near each other on the same material.

An example for a full bridge arrangement is the beam under pure bending shown in Figure 5.

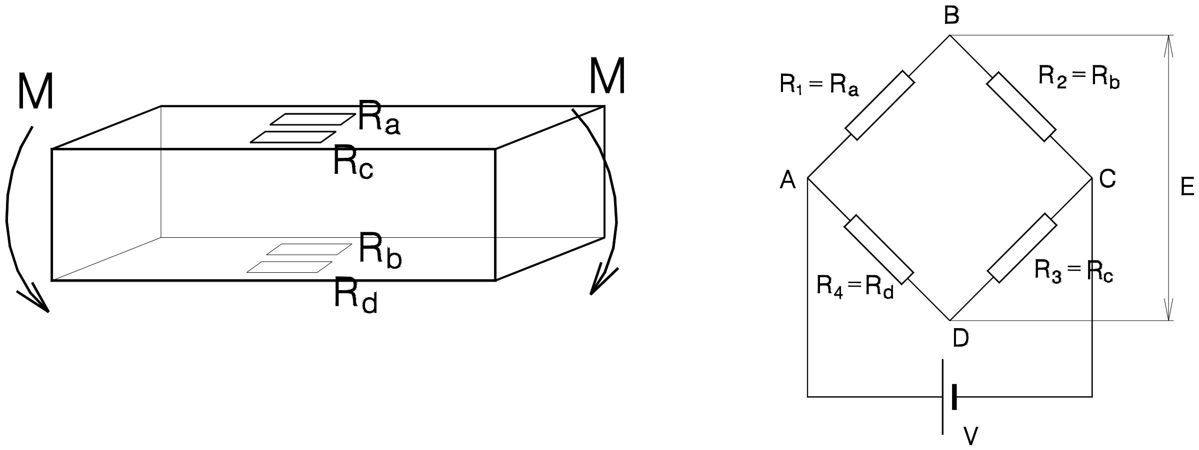

Figure 5 – Application for full bridge arrangement

The beam is under a system of pure bending moment M. The strains at the top and bottom surfaces are the same magnitude but opposite in sign. Therefore gages a and c will have a resistance increase during bending while gages b and d will have a resistance decrease of the same magnitude during bending. Since resistance changes due to the same temperature change will be cancelled out automatically using equation 3 we obtain an output of

$$\Delta E = k.\varepsilon.V \qquad \textbf{(8)}$$

If in addition to the pure bending moment, the structural member is subjected to a tensile force, the four gages will experience the same change in resistance due to the tensile force, in addition to change caused by the bending moment. Using equation 3 it is easily seen that we the arrangement shown in Figure 5 the effect of the tensile load is eliminated leaving only the bending components to be measured.

Correction for wheatstone bridge nonlinearity

As mentioned earlier, a nonlinearity effect must be considered when large strains (greater than 5%) are to be measured by using an unbalanced wheatstone bridge. For most commercial static strain indicators and signal conditioners it is necessary to provide a simple means for correcting the error due to the wheatstone bridge nonlinearity. The way how to do this is outside the scope of this module and the interested student is referred to 'Strain measurements and strain analysis – Akhtar S.Khan & Xinwei Wang' or 'Experimental stress analysis – J.W.Dally, W.F.Riley'.

Shunt resistor calibration

The interested student is referred to 'Strain measurements and strain analysis – Akhtar S.Khan & Xinwei Wang' or 'Experimental stress analysis – J.W.Dally, W.F.Riley'.

Student coursework

A good website on strain gauges and their applications can be found on:

http://www.vishay.com/brands/measurements_group/schools/edu.htm

Students are encouraged to pick up a project from the website and work through it as coursework for the module. Other exercises can be obtained from sheets available from the stress analyses laboratory and in consultation with the supervisor in charge. An idea of what can be done as coursework is given below:

Study of combined stresses, Flexure of I-beam, Study on stress concentrations, Analysis of soft drink can pressure, Measuring Young's modulus and Poisson's ratio, Importance of three wire attachment, Investigate the non-linearity of the Wheatstone Bridge, Measurement of Thermal expansion coefficient using strain gages, Plane shear measurement with strain Gages, etc