Strain measurement
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Stress and strain

Strain and stress are the result when it comes to external forces that are applied to a non-moving object.

Strain

Strain is defined as the amount of deformation that an object experiences compared to its original size and shape (the ratio of increase in length regarding original length)

\[ \varepsilon = \frac{\Delta L}{L} \]

The term strain is in most cases used to describe the elongation of a section.

Strain can be caused by the effect of a force.

Strain is a dimensionless quantity and is usually expressed in percentage. Typical measures for strain are less than 2 mm/m for steel and are often expressed in micro-strain units. One micro strain is the strain producing a deformation of one part per million.

Stress

Stress is defined as applied force per unit area

\[ \sigma = \frac{F}{A} \]
It usually occurs as a result of an applied force but is often due to the effects of force within a material or within a larger system.

For example, let's imagine a wire that is anchored at the top and hanging down. We apply weights to the end of this wire to pull it down, thus applying downward force. We can see that in the picture below, where $A$ is the original cross-sectional area of the wire, and $L$ is the original wire length. In this example, the material (wire) experiences stress that is called the axial stress.

![Diagram of axial stress](image)

The units are the same as pressure's, because the pressure is the special variation of stress. Despite that, stress is still more complex quantity than pressure, because it fluctuates with direction and with the surface it acts on.

We can calculate the stress ($\sigma$) by multiplying strain ($\varepsilon$) and the Young's modulus ($E$).

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

**Force**

$$Stress = \frac{Force}{Area}$$

$$Stress = E \cdot Strain$$

Therefore

$$Force = Area \cdot E \cdot Strain$$

Given that the elastic modulus (the Young's modulus) of steel is 210000 N/mm$^2$ and the cross section of the sensor is 139 mm$^2$ we get:
\[ \text{Force} = 139 \text{mm}^2 \cdot 2100 \text{N/mm}^2 \cdot \text{Strain} / 1E6 = 28 \cdot \text{Strain} \]
Young's modulus

Connection between stress and strain - the Young's modulus

The Young's modulus, also known as the tensile modulus or elastic modulus is a measure of the stiffness of an elastic material and is a quantity used to characterize materials.

It is defined as the ratio of the stress (force per unit area) along an axis over the strain (ratio of deformation over initial length) along that axis in the range of stress in which Hooke's law holds.

A material, whose Young's modulus is very high, is rigid.

The Young's modulus \([E]\), can be calculated by dividing the tensile stress by the extensional strain in the elastic (initial, linear) portion of the stress-strain curve:

\[
E = \frac{\text{Tensile stress}}{\text{Extensional Strain}} = \frac{\sigma}{\varepsilon} = \frac{F}{A_0} \frac{\Delta L_0}{L_0} = \frac{F \cdot L_0}{A_0 \cdot \Delta L_0}
\]

where

- \(E\) is the Young's modulus (modulus of elasticity)
- \(F\) is the force exerted on an object under tension;
- \(A_0\) is the original cross-sectional area through which the force is applied;
- \(\Delta L\) is the amount by which the length of the object changes;
- \(L_0\) is the original length of the object.

By the International System of Units, (SI), the unit of the Young's modulus is the Pascal (Pa or \(\text{N/m}^2\) or \(\text{m}^{-1}\text{kg} \cdot \text{s}^{-2}\)). The practical units used are megapascals (MPa or \(\text{N/mm}^2\)) or gigapascals (GPa or \(\text{kN/mm}^2\)).

In United States customary units, the Young's modulus is expressed as pounds per square inch (psi).

Measuring Modulus of Elasticity

Modulus of elasticity and yield stress are two frequent material properties that can be calculated from performing tensile tests with a mechanical testing system.

The procedure of Mechanical testing systems is that the selected material is clamped between two grips. The bottom grip is tightened on the surface while the top grip moves up at a certain displacement rate.

The testing system records the force that is needed to stretch the material and the suitable displacement of the grips. Engineers measure the original cross-sectional area of a specimen and the original length between the grips. After that, they are able to calculate stress from the force data and strain from the displacement data. All the data is then used to create
stress-strain diagrams as shown in the picture below.

**Stress-Strain Curve**

- **0.2% Offset Line**
- **Yield Strength Point**
- **Ultimate Tensile Strength (UTS)**
- **Breaking Strength**
- **Linear - Elastic Region**

**Tensile Specimens**

- Uniform Elastic Deformation
- Uniform Plastic Deformation
- Necking
- Fracture
Types of stress

1. Normal stress

We know two normal stresses - Tensile and Compressive stress. Tensile stresses are positive, compressive stresses are negative.

Normal stresses arise when tensile or compressive forces act against one another.

- Tension

On the picture below we can see a tensile load applied to a rectangular solid. The response of a rectangular solid to tensile loads is very dependent on the tensile stiffness and strength properties of the reinforcement fibres, since these are far higher than the resin system on its own.

- Compression

The figure below shows a composite under a compressive load. Here, the adhesive and stiffness properties of the resin system are crucial, as it is the role of the resin to maintain the fibres as straight columns and to prevent them from buckling.
2. Shear stress

The figure below shows a composite experiencing a shear load. This load is trying to slide adjacent layers of fibres over each other. Under shear loads, the resin plays the major role, transferring the stresses across the composite. For the composite to perform well under shear loads the resin element must not only exhibit good mechanical properties but must also have high adhesion to the reinforcement fiber. The inter laminar shear strength (ILSS) of a composite is often used to indicate this property in a multi-layer composite ('laminate').
Strain gage and gage factor

Strain gage

A Strain gage is a sensor whose resistance varies with applied force and in commonly used for load, weight, and force detection. It is basically a foil resistor, whose line resistance is proportional to the length and inversely to the area of the cross section. It consists of a small diameter wire, that is attached to a backing material (usually made of plastic). The wire is looped back and forth several times to create an effectively longer wire. The longer the wire, the larger the resistance, and the larger the change in resistance with. However, the change of the resistance is very small, so we need a good amplifier and measurement principle to detect such small differences. It is one of the most important tools of the electrical measurement technique applied to the measurement of mechanical quantities. Strain gages, that are glued to a larger structure under stress, are named Bonded gages. Typical strain gages have a resistances range from 120 Ω to 350 kΩ (unstressed) and are smaller than a postage stamp. This resistance may change only a fraction of a percent for the full force range of the gage, given the limitations imposed by the elastic limits of the gage material and of the test specimen. Forces great enough to induce greater resistance changes would permanently deform the test specimen and/or the gage conductors themselves, thus ruining the gage as a measurement device. That’s why, in order to use the strain gage as a practical instrument, we must measure extremely small changes in resistance with high accuracy. The ideal strain gage would undergo the change in resistance only because of the deformations of the surface to which the sensor is coupled. However, in real applications, there are many factors which influence detected resistance such as temperature, material properties, the adhesive that bonds the gage to the surface, and the stability of the metal.

Gage factor (GF or k)

If a wire is held under tension, it gets slightly longer and its cross-sectional area is reduced. This changes its resistance (R) in proportion to the strain sensitivity (S) of the wire’s resistance. When a strain is introduced, the strain sensitivity, which is also...
called the gage factor (GF), is given by:

\[ GF = \frac{\Delta R}{R \Delta L/L} = \frac{\Delta R}{R \varepsilon} \]

\[ \varepsilon = \text{Strain} \]

General examples of strain gages:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>gage FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal foil strain gage</td>
<td>2-5</td>
</tr>
<tr>
<td>Thin-film metal (e.g. Constantan)</td>
<td>2</td>
</tr>
<tr>
<td>Single crystal silicone</td>
<td>-125 to +200</td>
</tr>
<tr>
<td>Polysilicon</td>
<td>±30</td>
</tr>
<tr>
<td>Thick-film resistors</td>
<td>100</td>
</tr>
</tbody>
</table>

The gage factor does not rely on temperature, however it is important to know, that it only relates the resistance to strain if there are no temperature effects. The ideal strain gage would only change resistance due to the deformations of the surface on to which it was attached.
How to select the right strain gage?

1. Selection based on gage length:

   First let's explain what is a gage length.

   Gage length is the distance along the specimen upon which extension calculations are made. The gage length is sometimes taken as the distance between the grips.

   It ranges from 0.2 mm to 100 mm, but a length of 3 mm to 6 mm is generally recommended for the common applications.

   Select a shorter gage (≤ 3mm) if you are limited to mounting space, if a localized strain gradient needs to be measured (on a fillet, hole, or notch with a small diameter (< 25 mm), or if accuracy isn't critical.

   Select a longer gage (≥ 6mm) if you need to install gage really fast. If the gage is longer it is easier to install it, if heat dissipation is an issue (longer gage is less sensitive to heat), if the measured object has non-homogeneous material properties, such as concrete, if you want to save money. Gages with length of 5.0 - 12.5 mm are usually less expensive than gages of other lengths.

2. Selection based on gage resistance:

   The electrical resistance of a strain gage is directly related to its sensitivity. The higher is the resistance, the higher is then the sensitivity.

   Select a higher resistance gage (350 or 1000 Ω) if you need to have higher sensitivity or if you need certain compatibility with existing instrumentation.

   Select a lower resistance gage (120 Ω) if fatigue loading is an issue. Here it is really important to know, that lower resistance wire is larger in diameter, and more fatigue resistant. You can also choose this type if cost is an issue because 120Ω gages are usually less expensive than 350Ω gages.

3. Selection based on gage pattern:

   Before we start explaining gage patterns, it is important to explain what are Strain rosettes.

Strain rosette

A single strain gage can only measure in one direction. To overcome this, we use a strain gage rosette. It is an arrangement of two or more closely positioned gage grids, separately oriented to measure the normal strains along different directions in the underlying surface of the test part. Rosettes are designed to perform a very practical and important function in experimental
stress analysis. It can be shown that for the not-uncommon case of the general biaxial stress state, with the principal directions unknown, three independent strain measurements (in different directions) are required to determine the principal strains and stresses. And even when the principal directions are known in advance, two independent strain measurements are needed to obtain the principal strains and stresses.

Gage pattern refers to the number of grid and the layout of the grid.

Select a uniaxial strain gage if you need to measure only one direction of strain or if you are limited with money, because two or three single uniaxial strain gages are usually less expensive than a bi-axial or tri-element strain gage.
Select a bi-axial strain rosette (0°-90° Tee rosette) if you need to measure principal stress, that means that principal axes are known.

Select a three-element strain rosette (0°-45°-90° rectangular rosette or 0°-60°-120° delta rosette) if you want to measure principal stresses and you don't know the principal axes.

We know two different layouts in multi-axial strain rosettes: planar and stacked.
Select a strain rosette with planar layout, if you have problems with heat dissipation or you have critical accuracy and stability. Planar layout has each gage closer to the measuring surface and no interference in between.

Select a strain rosette with stacked layout, if the strain gradient is large. Stacked layout measures strain at the same point or if you are limited in mounting space.
Mounting of the strain gage

The mounting of the strain gage is not a difficult task, if we follow suggested procedure. Strain gages are fragile and can be damaged easily.

For mounting a strain gage we need illuminated magnifier, electrical grade solder, rosin soldering flux, epoxy adhesive, cyanoacrylate adhesive, lacquer thinner, acetone or alcohol, masking tape, toothpicks, tweezers, awl, ruler, fine gauge tinned-copper lead wires and ohmmeter.

Important: never touch a gage with your fingers!

Let’s take a look at YouTube video below, that will show us how to install a strain gage.

Video was created by Mechatronics department in the university of Jordan.

Strain gauge installation

A short story about the strain gage connections really fits in this context.

Most people are likely familiar with Murphy’s Law. It originally states that “Whatever can go wrong, will go wrong”. This is very well known, but what is not known so well is that it originates from the strain gage measurements. The “inventor” of this law, Capt. Ed Murphy made a strain gage measurement system for a g-force testing system at Edwards Air Force Base, where the maximum g force, that the human body could take, was to be tested. As a side-note, a real human was used, and the maximum force was 40 g.

The result of the first measurement was zero, simply because the strain gages were connected in such a way that they canceled out each other. Capt. Ed Murphy blamed his assistant for the error, who had connected the gages in the wrong way. The other, even more interesting part of the story for the process of measurement was that Murphy simply declined a verification of the system, which was offered to him before performing the test.

The point of this story is this: Connect - CALIBRATE - VERIFY - Measure. If Capt. Ed Murphy had followed this procedure Murphy’s Law would not have been invented (at least not for that occasion).
Wheatstone bridge

Before we continue our discussion about strain gages we must acquaint ourselves with the Wheatstone bridge circuit. It is a bridge circuit for measuring electrical resistances and it was made popular after Sir Charles Wheatstone proposed the method in 1843. The Wheatstone Bridge circuit is nothing else than two simple series-parallel arrangements of resistors connected between a voltage supply terminal and the ground producing zero voltage difference, when the two parallel resistor legs are balanced. It has two input terminals and two output terminals consisting of four resistors configured in a diamond. You can see the typical drawing of Wheatstone bridge in the picture below. It is suitable for measuring small changes in resistance, making it good for strain gages.

The below example shows how the string gages utilize the Wheatstone bridge circuit. It also shows how strain gages can be bonded to a test specimen.

If there is no force applied to the object, both strain gages have equal resistance and the bridge circuit is balanced. But when a downward force is applied, the object will bend downward and stretch the strain gage #1 and compress the strain gage #2 at the same time. The bridge will be unbalanced and a voltage difference occurs. This is shown nicely in the second picture.
BRIDGE UNBALANCED

STRAIN GAGE #1

STRAIN GAGE #2

FORCE

R#1

R#2

BRIDGE UNBALANCE
Strain gage wiring systems

There are several configurations for basic measurements. First, we need to know the special effects of the materials - that is when the material is stretched, the material (usually) gets thinner in the other (two) directions. The ratio of transverse strain to extension strain is called Poisson's ratio $\nu$. When strain gages are positioned 90 deg. towards each other, it becomes very important to know the ratio of transverse strain and to include this in the equation. The Poisson's ratio is 0.27 to 0.31 for steel (usually 0.3 is used) and 0.33 for aluminum.

The following table shows several basic configurations for the gages. Basically, the configurations are divided into quarter, half and full bridge circuits.

<table>
<thead>
<tr>
<th>MEASURES</th>
<th>TYPE</th>
<th>BRIDGE</th>
<th>EQUATION</th>
<th>BRIDGE FACTOR</th>
<th>LINEAR</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>tension, compression</td>
<td>quarter</td>
<td>$\frac{k}{4 + 2 \cdot \nu}$</td>
<td>1</td>
<td>no</td>
<td>Single gage measuring tension and compression - basic configuration</td>
<td></td>
</tr>
<tr>
<td>tension, compression</td>
<td>half</td>
<td>$\frac{k}{4 + 2 \cdot \nu + \nu}$</td>
<td>$(1 + \nu)$</td>
<td>no</td>
<td>One gage in principal direction and one in transverse direction - usually used for temperature compensation</td>
<td></td>
</tr>
<tr>
<td>bending</td>
<td>full</td>
<td>$\frac{k}{2}$</td>
<td>2</td>
<td>yes</td>
<td>Two gages with opposite strain - usually used for measurement of bending</td>
<td></td>
</tr>
<tr>
<td>tension, compression</td>
<td>half</td>
<td>$\frac{k}{2 + \nu}$</td>
<td>1</td>
<td>no</td>
<td>Two gages with same strain - usually used for bending cancellation</td>
<td></td>
</tr>
<tr>
<td>tension, compression</td>
<td>full</td>
<td>$\frac{k}{2 + \nu + \nu}$</td>
<td>$(1 + \nu)$</td>
<td>no</td>
<td>Two pairs of gages where one is in the principal direction and the other one is in transverse direction - used in temperature compensation and tension cancellation</td>
<td></td>
</tr>
<tr>
<td>bending</td>
<td>full</td>
<td>$\frac{k}{2}$</td>
<td>2</td>
<td>$(1 - \nu)$</td>
<td>yes</td>
<td>Two pairs of gages where one is in the principal direction and the other one is in transverse direction - used in temperature compensation and tension cancellation</td>
</tr>
<tr>
<td>bending, torsion</td>
<td>full</td>
<td>$k \cdot \nu$</td>
<td>4</td>
<td>yes</td>
<td>Two pairs of gages in opposite strain - usually used for measurement of bending</td>
<td></td>
</tr>
</tbody>
</table>

A strain gage Wheatstone bridge is configured with quarter, half or full bridge system according to the measuring purpose.

Quarter bridge system

If we look at a quarter bridge system, we can see that strain gage is connected to one side of the bridge and fixed resistors are connected to each of the other 3 sides. This system can easily be configured, and that’s why it is widely used for general stress/strain measurement. The quarter bridge 2-wire system is shown in a first figure above is largely affected by lead wires. Therefore, if large temperature changes are anticipated or if the lead wire length is long, then the quarter bridge 3-wire system shown in the second figure above must be used.
Half bridge system

The half bridge system is used to eliminate strain components other than the target strain; according to the measuring purpose. With the half bridge system, strain gages are connected to the bridge on adjacent or opposite sides, with fixed resistor inserted on the other side. This gives us the option of configuring the gages in two different ways. The first one is the active-dummy method, where one strain gage serves as a dummy gage for temperature compensation, and the active-active method, where both gages serve as active gages.

Full bridge system

The full bridge system has strain gages connected one each to all 4 sides of the bridge. This circuit ensures large output of strain gage transducers and improves temperature compensation as well as eliminates strain components other than the target strain.
4 and 6 wire circuit

4 - wire circuit

The 4-wire circuit is used for strain gage measurement with short lead wires. Its limitation is that the supply voltage is exact on the connector of the amplifier.

6 - wire circuit

The 6-wire circuit is recommended for the installation of long wires to the sensor. The sense wires are connected to the excitation on the side of the sensor, so the amplifier can “sense” or measure the excitation voltage and adjust it to the higher level that it is exact on the side of the sensor. This improves a lot of amplitude accuracy of the measurement.
Quarter bridge measurement of stress and strain in Dewesoft

For this experiment we will connect tuning fork to a Sirius device. Tuning fork has attached single gage.

We will be measuring two different Physical quantities - strain and stress.

Quarter bridge setup

Let’s take a look at a quarter bridge setup in Dewesoft X using DAQP-BRIDGE-A.

A single strain gage is attached to the tuning fork and we are measuring Strain.

Picture below shows us how the specification of a strain gage looks. We can see that the resistance of the strain gage is 120 Ohms and the gage factor k is 2.07.

When selecting strain gages, we can typically choose from 120 or 350 Ohms. 120 Ohms gages will have less power consumption and less heating while 350 Ohms will have large signals and therefore work better with longer cables.
1. Measurement of strain

For our measurement, we will use 350 Ohm strain gage.

This is how the channel setup looks like:

First we must set the quarter bridge with 350 Ohms as the input type. This means that the single bridge will be the real gage while other three gages will be internal precision resistors. Now, the input scaling is in mV/V.
Then we can freely select the Excitation voltage. A higher excitation voltage will increase the signals and therefore reduce the noise. This will also cause more gage self-heating and will increase the power consumption. All strain gages have a certain limit for the excitation voltage, so check this prior to connecting the sensor not to burn it. Higher excitation voltages are, therefore, recommended for longer lines.

The next step is to enter the gage factor (k) and Bridge factor from the specification. Since this is only a quarter bridge, we can enter the bridge factor as 1.

The scaling changes from uV/V to um/m. We can now enter the range in units of relative deformation.

We have the tuning fork connected with three wire connection. The three wire connection allows us to cancel out the effect of wire resistance. We call this effect the Lead wire compensation. Especially with long cables, the wire can significantly reduce the sensitivity of the gage. The third wire combined with the shunt calibration allows us to measure this resistance and correct this error.

The shunt calibration can be used to measure and correct the resistance in this case. We need to choose the Bridge cal scaling and click the Compensate button. Shunt calibration takes a while since it has to set several configurations and measure back the results. After that, the wire resistance measurement shows in the drawing, the Correction factor is shown and, if possible, the Excitation voltage level is raised to still meet the required sensitivity of the gage.

As the last step, we set the Low-pass filter of the amplifier to 10 kHz to be able to see the tuning fork natural frequency, which is 440 Hz (A4 tone).

2. Measurement of stress

Now let's make another channel setup, this time we will be measuring stress and this is how the channel setup looks like:
When we are measuring Stress we set everything completely the same as we were measuring Strain, except Physical quantity in General settings and Settings in right bottom corner.

Depending on which bridge mode we choose in General amplifier settings, we can afterward choose graphically presented bridge configuration, and also material for using the correct Young's modulus.

That's how another error source is eliminated.
NOTE: All this Gage type options and Material options depend on the Bridge model!
Simple measurement with tuning fork

Let’s take a look at the recorder. If a static force is applied on the tuning fork, we can see the changing offset of the signal. We might also try hitting the tuning fork so it makes a sound to reflect the natural frequency of the tuning fork (the conventional way it is used). We can see this as a high-frequency vibration with falling amplitude because of air friction and friction in the fork.

When looking at the FFT screen (let’s change it to the logarithmic scale that can be used to see all the amplitudes in a nice way), we can see that there is an obvious peak at approximately 440 Hz. We can also place a cursor at this point by simply clicking on the peak in the FFT. The frequency shown is 438.8 Hz. It is not exactly 440 because the tuning fork used here surely isn’t what it should be after many years of use, but also because the FFT has a certain line resolution.

This line resolution depends on the sampling rate and the number of lines chosen for the FFT. If we want to have a faster response on the FFT, we would choose fewer lines, but we would have a lower frequency resolution. If the user wants to see the exact frequency, it is necessary to set a higher line resolution. This is well described in reference guide, but a simple rule of thumb is: if it takes 1 second to acquire the data from which the FFT is calculated, the resulting FFT will have 1 Hz line resolution. If we acquire data for 2 seconds, line resolution will be 0.5 Hz.
This is also a perfect example to take a look how to use the filters in Dewesoft X. Clearly, there is one part of the signal in the form of the offset (static load) and one part in a form of dynamic ringing with a 440 Hz frequency.

If we want to extract those two components from the original waveform, we need to set two filters - one low pass and the other high pass. So we add two filters in the Math section.

1. First, we set the input channel (AI 0) in this case. Then we set it on Low pass, 6th order filter and we set the cutoff frequency $F$ high to 200 Hz.

$$V = R \times I$$

order filter and we set the cutoff frequency $F$ high to 200 Hz.
This is so that all the signals below 200 Hz frequency will pass and all the frequencies above this will cut.

\[ I = \frac{R}{V} \]

2. The second filter is set to High pass 6th order with the same cutoff flow frequency

\[ R = \frac{I}{V} \]
If we show those two filters on the recorder, we can see that the signal is nicely decomposed to the static load and dynamic ringing. The user can use this technology to cut off unwanted parts of the signal or to extract wanted frequency components of the certain signal.
At this point, it might be worth noting that IIR filters are used where we want higher calculation speeds and cutoff rates are needed. We can also use FIR filters if we don't want to have any phase shifts. More details can be found in the Filter comparison section of FIR filter in the user's manual.
Full bridge measurement of strain and force in Dewesoft

For this experiment, we will connect off-the-shelf load cell with a full bridge connection to a Sirius device.

Dog bone specimen for measuring force

To help engineers select the right material for their device, many materials have been tested a lot of times. All the material properties were then published in material handbooks. But not just that. Engineers have put a set of standards into practice to ensure that testing is directed the same way no matter which material is being used. On this point, it is important to explain why is the specimen in the shape of the dog bone with different ends. Geometry of the specimen is really important! The rectangular shape of the specimen would cause higher stress states at the grips. To solve this error, engineers developed special shape - Dog bone. This doge's bone is larger at the top and bottom where we attach the grips to the specimen. Cross sectional area is smaller between those two grips. And why? Explanation is simple. Smaller cross sectional area allows the stress to be concentrated in the center of the specimen, and that's why eliminate the effects of the grip. By using this shape of a specimen, engineers can be 100% sure that the stress measured by the testing system is the same as the stress state that was actually experienced by the material.
Example 1

Stress-Strain-Diagram with Characteristic Values for Steel with the Young’s modulus [E] = 210 MPa.

Figure below is a great example of dog bone-shaped specimen and a typical stress-strain diagram for a ductile, elastic material such as steel. Engineers gather much useful information from this diagram to learn about the behavior of a material, including its modulus of elasticity and yield stress.

- Elastic range is defined by the linear portion of the stress-strain curve.
- Plastic range is the portion of the diagram to the right of the elastic region; this is the region of permanent deformation. If a material is stretched into this region, then it starts to permanently deform.
- Yield stress is the minimum stress that causes permanent deformation.
- Ultimate tensile stress is the maximum stress that a material can withstand; it is the maximum point on the diagram. At this point, necking begins, and the material starts down a slippery slope to ultimate failure.
- Necking is a localized decrease in cross sectional area.
- Fracture stress is stress in which the material fails. This is the last stress state that a specimen experiences before it fractures.
Let's look more closely at this graph and explain the most important features that engineers use and record.

- $E = 193,000 \text{ MPa}$
- $R_{p0.2} = 238 \text{ N/mm}$
- $R_{eL} = 238 \text{ N/mm}$
- $R_{m} = 314 \text{ N/mm}$
- $R_{eH} = 281 \text{ N/mm}$
- $A_g = 24.4\%$
- $A = 44.7\%$

Graph showing:
- Stress (N/mm)
- Long Strain (%)
- Steel tensile specimen
- Tensile load direction
- Neck
- Elastic range
- Plastic range
- Ultimate tensile strength
- Yield stress
- Fracture stress

Diagram illustrating the stress-strain curve with key points marked.
Full bridge setup

For the full bridge sensor we will use a “home made” force sensor.

The sensor is built from two xy strain gages, where one gage is oriented in the principal direction and another one in a transverse direction.

This sensor is therefore temperature compensated and has bending cancellation.

Let’s do a step by step calibration of such a configuration. First of all we change the Input type to Full bridge

\[ I = \frac{V}{R} \]

and Balance sensor

\[ V = R \times I \]

is performed. If the bridge zero is not successful, we should choose the highest possible Range, perform zero, then switch to the wanted range and perform zero again. Then we set the Lowpass filter. Since this example will measure more or less static measurements in a low region of the probe, the results can be enhanced by using a very low lowpass filter. In this case, it is set to 100 Hz

\[ I = \frac{R}{V} \]
Next we set the Strain scaling to used and set the k factor of the gages to 2 and the Bridge factor to 2.6. The value of 2 is read from the strain gages data sheet. The value of 2.6 is a bridge factor from the table of bridge configurations. Now the input values are strain in um/m.

Now we need to do the final Scaling by function since the force should be measured in kN. Now it’s time to do some calculations using following equations:

\[
\text{Stress} = \frac{\text{Force}}{\text{Area}}
\]

\[
\text{Stress} = E \cdot \text{Strain}
\]

Therefore

\[
\text{Force} = \text{Area} \cdot E \cdot \text{Strain}
\]

Given that the elastic modulus (the Young’s modulus) of steel is 210000 N/mm² and the cross section of the sensor is 139 mm² we get:

\[
\text{Force} = 139mm^2 \cdot 210000N/mm^2 \cdot \text{Strain}/1E6 = 28 \cdot \text{Strain}
\]

Factor 1E6 is there because the strain is measured in um/m and we need to have a scaling factor for this unit.

Now we have the real data scaled in N. The last thing, to do, is to select the measurement Range based on the input. In this case, the lowest range will be more than enough for the measurement.

The Short and Shunt button is for checking the strain gage. The Short is used to short the pins on the input and measure the bridge offset. The Shunt (which is also used in the shunt calibration routine) can be used to see if the bridge is reacting - so to check if the connections are working.

In the picture below you can see the setup for measurement of force. Instead of typing in the k factor, we can type in the sensitivity of used strain gage. In our case, the sensitivity is 0,23 mV/V/kN.
Full bridge measurement of force

Just for this Pro training course we've made a short in-house competition in breaking the load cell apart. The measurement range of this load cell is 30kN or approximately 3 tons, so it is quite reasonable, that none of the competitors was successful.

Just to make the entire measurement bigger fun, was the load pulled by our students and a girl! We have also plugged in USB camera, to capture video while pulling the load.

Let's take a look at the results.

Boys did a great job, and pulled 466 and 397 N, which is 46,6 kilograms and 39,7 kilograms.
On the picture below you can see that girl can beat everyone if she is a great athlete or if she simply knows how to use math in Dewesoft. :)
Signal conditioning for strain gages

In electronics, signal conditioning means manipulating an analog signal in such a way that it meets the requirements of the next stage for further processing. Signal conditioning is needed before a data acquisition device can effectively and accurately measure the signal.

Signal conditioning can include amplification, filtering, converting, range matching, isolation and any other processes required to make sensor output suitable for processing after conditioning.

Filtering is the most common signal conditioning function, as usually not all the signal frequency spectrum contains valid data. The common example is 60 Hz AC power lines, present in most environments, which will produce noise if amplified.

Signal amplification performs two important functions: increases the resolution of the imputed signal and increases its signal-to-noise ratio. For example, the output of an electronic temperature sensor, which is probably in the millivolts range is probably too low for an analog to digital converter (ADC) to process directly. In this case, it is necessary to bring the voltage level up to that required by the ADC.

Signal isolation must be used in order to pass the signal from the source to the measurement device without a physical connection: it is often used to isolate possible sources of signal perturbations. Also notable is that it is important to isolate the potentially expensive equipment used to process the signal after conditioning from the sensor.
Shunt calibration

We use shunt calibration for two purposes. To check if the measurement chain is working and to cancel out the effect of lead wire compensation.

Bridge balancing

Bridge balancing is the function of the bridge amplifiers to eliminate the bridge sensor offset. Mathematically it means to simply remove the initial offset of the sensor on the side of the amplifier. For the demo, we connect a quarter bridge strain sensor.

In the scope screen above the unscaled value currently read (left side) is 0.9 mV/V. That is because the strain gauge does not have exactly 350 ohms, which is normal, due to tolerances.

Click on ‘Balance sensor’ to zero the bridge.

The unbalance will be measured and shown. Amplifier will choose the right setting to achieve full-scale range.
The input signal is now 0 mV/V

We normally do the balancing just before we perform the measurement. If we want to do the balancing on number of different channels, we can do that by using the GROUP OPERATIONS (described at the end of the topic).

**Short on**

When sensor balance is used, we can always check what is the value of the unbalance by using the short function. When using the SHORT ON operation, the pins 2 and 7 (the input pins of the amplifier) are internally shorted.

We simply click "Short on".

![Sensor balance screen](image)

The resulting value will show the sensor unbalance.

**Disable the short again by clicking "Short off"**

![Sensor balance screen](image)
Please note that we can remove the sensor balance by clicking the Reset button. After that, the sensor offset will be removed and the amplifier will be set into the initial state.

On the screen, we can see the unbalance of the sensor again, which is 0.9 mV/V.

"Balance" and "Reset" are, therefore, opposite operations.

Zero

There is also a function called "Zero" which is similar to "Balance sensor". Let's look at the difference below.
Imagine, we have a force transducer with a strain full bridge output. It will measure the weight in our experiment. In the first picture, we measure the unbalance of the bridge sensor, e.g. 35 N. Let's do a “Balance sensor”. The output is now 0 N. A vehicle is put on the test bed. We measure its weight, which is 12 000 N. For our measurement only the changing of the weight is of interest, so we cancel out the fix offset with the Zero function.

Click the “Zero” button in Channel Setup (can be reset by right mouse-click). The output is now zero again. Note that this is a pure software subtraction. If the range was set to "Automatic", the range is automatically adapted to -52000...+28000.

The range can be set to "Automatic" in the channel setup window of the appropriate channel (right mouse-click).

Now all offsets are canceled and we start the measurement. This function can also be accessed in the Measure mode (but NOT while storing!).

Shunt calibration

With shunt calibration we can:

- check if the amplifier is working properly (excitation and value readout);

- check if strain gauge is connected and working properly;

- we can compensate the length of the lead wires.

The SHUNT ON operation is meant for checking if the connected strain gauge is OK. From the wiring schematic in Dewesoft X, you see that the amplifier already comes with the integrated shunt resistor.
The idea behind is to "shunt"/connect a resistor of known value parallel to one resistor of the bridge to achieve a known, calculable unbalance.

With the "Shunt calibration," we can automatically check the measured value against a predefined one (from sensor database or TEDS). For the measurement, this internal shunt resistor is disconnected again of course.

Let's check out the formulas:

\[ R_1 = R_2 = R_b \]
R3 and R4 are part of the bridge completion, mounted internally in the amplifier. The R1 is the connected strain gauge. The R2 is also mounted internally in the amplifier together with the shunt Rs. With a 350 ohms quarter bridge and an internal shunt resistor of 175kohm (SIRIUS STG module) the expected unbalance should be:

\[ V_s = \frac{250}{175000} = \frac{0.5mV}{V} \]

The resistor value in one leg, when shunt is connected, is calculated from the equation of parallel resistors:

\[ \frac{dR}{R} = \frac{1}{\left(\frac{1}{R2} + \frac{1}{Rs}\right)} = \frac{1}{\left(\frac{1}{175000} + \frac{1}{350}\right)} = 349.40139 \]

From the equation of the bridge we get the bridge unbalance:

\[ V_s = \frac{dR}{R} \cdot \frac{1}{4 + 2 \cdot \frac{dR}{R}} = \frac{349.40139}{4 + 2 \cdot 349.40139} = 0.498mV/V \]

If the bridge factor is 2, the resulting strain will be:

\[ \frac{Dl}{L} = \frac{V_s}{V_{exc} \cdot \left(\frac{4}{k}\right)} = 0.5 \cdot \frac{4}{2} \text{mm/mm} = 1 \text{mm/m} = 1000 \mu \text{m/m} \]

If the bridge is out of balance, we need to click first on "Balance Sensor", because the formula is only valid on a balanced bridge (both \(R_b = 350\) ohms).

![Sensor unbalance](image)

Then we click "Shunt on".

![Amplifier](image)

The output value comes very close to the expected value (0.495 mV/V).
But how big is the error exactly?

We can define the size of this error by making shunt cal check. Before we do that, we need to make needed SHUNT CAL PREPARATION.

Shunt cal check is done on scaled values, therefore, we take a look on the strain scaling. The max input from the graph above is 2 mV/V; the max scaled output signal is 4000 um/m. So, the scaling factor is 2000.

Our target value of 0.495 mV/V would equal (x 2000) = 1000 um/m.

After all the preparations are done, we can make SHUNT CAL CHECK.

The result of our shunt cal check looks very promising in this case (-0.2 %). That means that the strain gauge is OK.
Lead wire effect

In some cases, strain gauges are mounted away from the measuring equipment. This distance increases the possibility of errors because of changes in temperature and lead desensitization. Therefore, lead-wire resistance changes. If we have a two wire installation, that is shown in the picture below, two leads are in series with the strain gauge and any change in the lead-wire resistance can’t be distinguished from changes in the resistance of strain gauge.

But this can be fixed. We can correct the lead-wire effect by adding additional - third wire. This is shown in the next picture.

In this configuration, the third wire acts like a sense lead. No current is flowing through this wire. This option of wiring strain gages to a bridge cancels one part of the extension wire errors. If we look from more theoretical side, if the lead wires, that run to the sensor, have the same nominal resistance, temperature coefficient and temperature, full compensation exists. In real life, wires have a tolerance of about 10% an a three-wire installation doesn’t eliminate the two-wire errors completely. But it sure reduces it. If the lead- wire resistance doesn’t exceed the gauge resistance and is small in comparison to it, that error isn’t considerable. But if the lead-wire resistance exceeds 0.1% of the nominal gauge resistance, this source of error becomes significant. Therefore, in industrial applications, lead-wire lengths should be minimized or eliminated by locating the
transmitter directly at the sensor.

Lead wire compensation

If you have a long cable connected to the sensor and "quarter bridge 3 wire mode", Dewesoft X can also cancel out the wire resistance. (In the other modes the wire loss is already cancelled because Sense and Excitation lines are connected directly to the sensor). In the picture below you can see a quarter bridge strain gauge with 3-wire connection. In each of the 3 lines, we have built in a resistor of 6 ohms for showing the principle.

Click the "Compensate" button.

The correction factor will be calculated (1,032 in our case) and the measured resistance (11,2 ohms) displayed.

Note, that this function is only available, if the Shunt resistor inside the module is connected to the Exc+ line, which is chosen by default.

OK, let's make a short experiment to show the difference between 1m and 100m of wire.

First we will make Lead wire compensation using 1m long wire with tuning fork at the end.

This is how the setup looks like:
When we press the "compensate" button on the right side of the screen, we get this:
Now, let's make the same thing, using 100m of wire.

We connect everything together and the setup looks like this:

![Diagram of the setup](image)

When we press the Compensate button, we receive the lead wire compensation value that differs from the value when we were using 1m long wire.
Group operations

We have several group operations (Channel actions). We can find them in Channel setup.

By pressing the

button, we can add even more Channel actions,

Let’s add Lead wire compensation. The amount of visible buttons depends on the amplifier type that we are using.

For the following steps, we need to activate more columns in the channel setup table. Click on one of the small icons and select “Edit columns”: 
Select the fields "ShCal target", "ShCal result", "ShCal error" and "Group".

We will show the group operations in one short measurement..

For this experiment, we will use the Sirius instrument. We will start our measurement by connecting two tuning forks (quarter bridge, 3 wires, 350 ohms). Tuning forks can be connected to Sirius via STG adapters.

Unfortunately, the Sirius, that we are using, doesn't have two STG channels, so we will connect one tuning fork via STG and the second one via STG to MULTI converter. We already know how to set everything for 3 wire, 350 ohm quarter bridge connected via STG.

This is the setup:
The settings are a bit different when it comes to connection via STG to MULTI converter.

Let's take a look.
We are able to choose Bridge measurement and bridge mode. But when we try to choose internal 175 kΩ bridge shunt value, this option isn’t available. On this point, we need to explain one great feature of Dewesoft X. Dewesoft X recalculates all the values, no matter which bridge shunt you choose. That means, that the software automatically takes care if there are different resistor values. In the General information tab, we have the 59.88 kΩ resistor present, but if we mark the Use custom shunt resistor, we can type in the correct value of the used resistor.

When entering the resistor value, the field gets yellow. We confirm the value by pressing <Enter>.

The software will then automatically recalculate the values, according to the given (Bridge shunt) and chosen resistance values. The asterisk (*) symbol after the result indicates that the check has been performed with a different resistor value than was physically available.
Calculation of shunt cal resistance

For this example, we take the well known formula and calculate the shunt result with 175 kΩ shunt resistor.

Scaling factor = 4000 μm/m / 2 mV/V = 2000

Shunt cal resistance = Vs = 250 / (175000/350 + 0.5) = 0,4995 mV/V * 2000 -> 1000 μm/m

175 kΩ = 175000 Ω = custom shunt resistance

In group operations, we can perform different operations, for example group bridge balance, group shunt cal check etc. Results of our group operations are shown in columns that we have added.

We can also make group operations with different groups. We do that by simply assigning one channel to ’Group 1’, and the other to ’Group 2’.
Now you can apply (bridge) operations group-wise.

We can also perform group operations in Measure mode, so let’s go there first. There we will see two new buttons: Zero and Amplifier. If the “Zero” button is not there, then sensors from the sensor database / TEDS sensors are most likely used, and changing the offset is not allowed. Check sensor settings in Channel setup or Sensor editor. If the “Amplifier” button is not there, no amplifiers are set to “Used” in channel setup. Now you can do a selective “Balance” on the selected group or on “All chs.”

Shunt/Short at the beginning and end of measurement

At the end of a measurement, you may want to check if the strain gauge and the amplifier are still OK. You also want to see, if the bridge has drifted over time due to temperature or other effects.
Start the measurement and click the Store button. The “Zero” button will disappear, because zeroing also changes the channel min/max limits, and that is not allowed during measurement. Also, balancing the bridge is not possible at this state anymore.
Do a “Short on for 1s”, wait a little bit, then press “Shunt on for 1s”.

![Image of balance sensor settings](image1)

![Image of short/short on settings](image2)
At the end of the measurement, — when you are still storing (!) — do again a “Short on for 1s” followed by a “Shunt on for 1s”. Stop the measurement and go to Analyse mode. Activate the cursors in the properties of the recorder instrument (on the left side).

Move the white cursor I to the Short position at the start, and cursor II to the Short position at the end (grey arrows). You can also lock the cursors to not lose them when zooming in and out of a longer measurement.

The Delta will be shown on the right side. In our case, it is 0,0 — measurement OK.