

EXPERIMENTAL METHODS PRACTICAL TASKS

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Task 1: Measurement of a rubber part stiffness

1. Task

- Measure the stiffness (i.e. dependence of the force on the compression) of the rubber part – silent block - at three different compression speeds: 2 mm/s, 10 mm/s and 50 mm/s.
- The compression value will be determined according to the dimensions of the silent block specimen (about 5 to 10 mm).
- Create a graphical representation of the measured dependence (force on the compression).
- Determine the stiffness of the rubber part and evaluate whether the dependency is linear and whether the stiffness is affected by the compression speed.

2. Theoretical analysis of the experiment

Definition of stiffness

Stiffness is a physical quantity that indicates the **dependence of the compression of a compressed body on the acting force**. It represents a characteristic of each compressible body. Unlike the elasticity modulus, it applies to the whole body, not just the material it is made of. Its value is determined based on the used material and the shape of the body.

Stiffness is defined by the equation: $k = \frac{\Delta F}{\Delta l}$ [Nm^{-1}]

where ΔF is the increment of the force acting on the body

Δl is the body compression increment

Generally, the dependence of the body compression on the acting force is a non-linear curve, in special cases, the dependence may be linear for certain force ranges, e.g. in case of a steel spring. For bodies made of special materials (porous materials - foams), their stiffness may also depend on the pressing speed.

Equipment needed for the experiment:

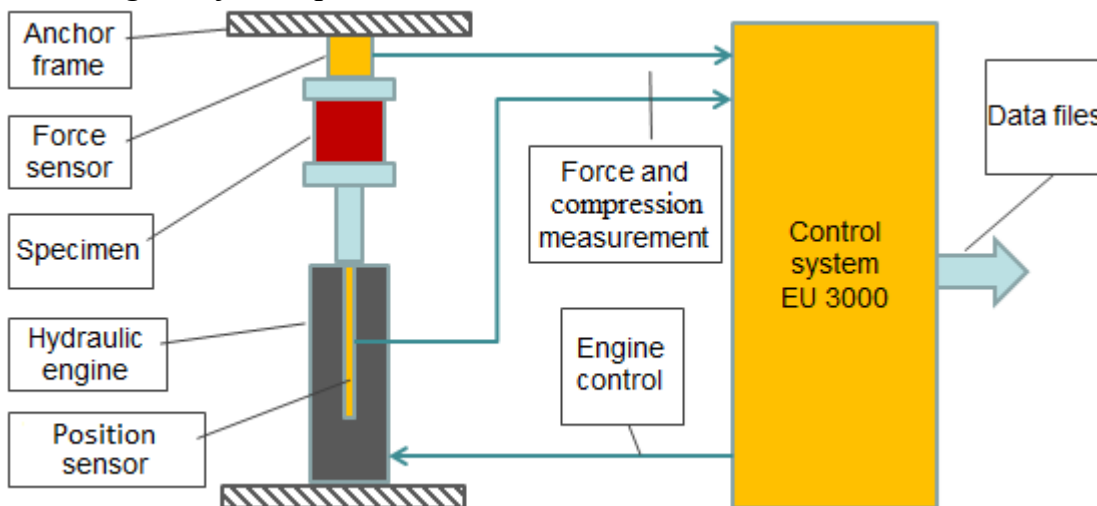
- Equipment for mechanical compression of the rubber part with a stroke of approx. 10 mm, adjustable speed up to 50 mm/s and an assumed force up to 10kN
- Anchoring frame
- System for measuring and recording the progress of the required values - compression and force
 - o Position sensor (for compression measurement)
 - o Force sensor
- System for processing the results - data files
 - o PC and SW (matlab or spreadsheet editor, e.g. Excel, Calc)

3. The actual experiment procedure

Equipment used:

- Hydraulic engine Inova AH 25-250 (max.: 25kN, 250mm, 1m/s)
- Anchoring frame
- Inova EU 3000 control system to the hydraulic engine control and data measuring and recording
- Position sensor integrated in the hydraulic engine
- Force sensor GTM

Block diagram of the experiment:



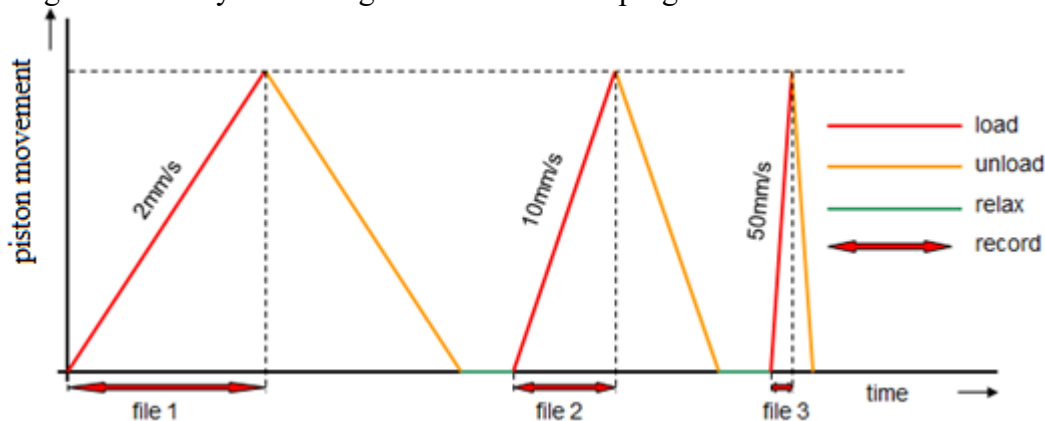
Preparation of the experiment:

The Inova control system is used to control the hydraulic engine and to record data.

The experiment requires:

- Programming the movement of the hydraulic engine according to the requirements
- Settings the measuring and recording parameters of compression and force

Diagram of the hydraulic engine movement and progress of the measurements:



Experiment procedure:

- Inserting the specimen into the testing equipment
- Manual setting to the initial position
- Reset the value of the position sensor
- Automatic pressing at three different speeds while measuring and recording data
- Manual setting to the mounting position and removing the specimen

4. Processing the measured data and presenting the results

Data files system:

Practically all the testing systems enable saving of the measured data in data files. These files can be created directly in a generally readable format (txt, csv), sometimes they are initially stored in a special binary format (speed of storing, amount of data) and in this case, the data can be exported from this format for further processing.

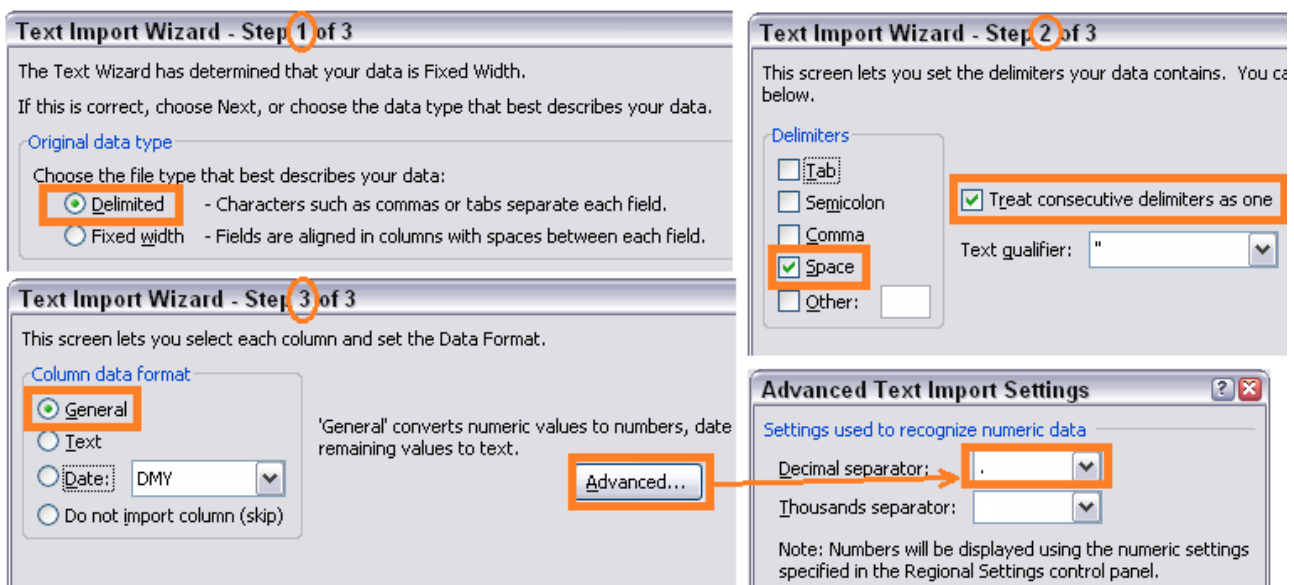
In general, the data file contains a header with a description and the time sequence of the measured quantities, usually accompanied by a time axis.

Example of a data file:

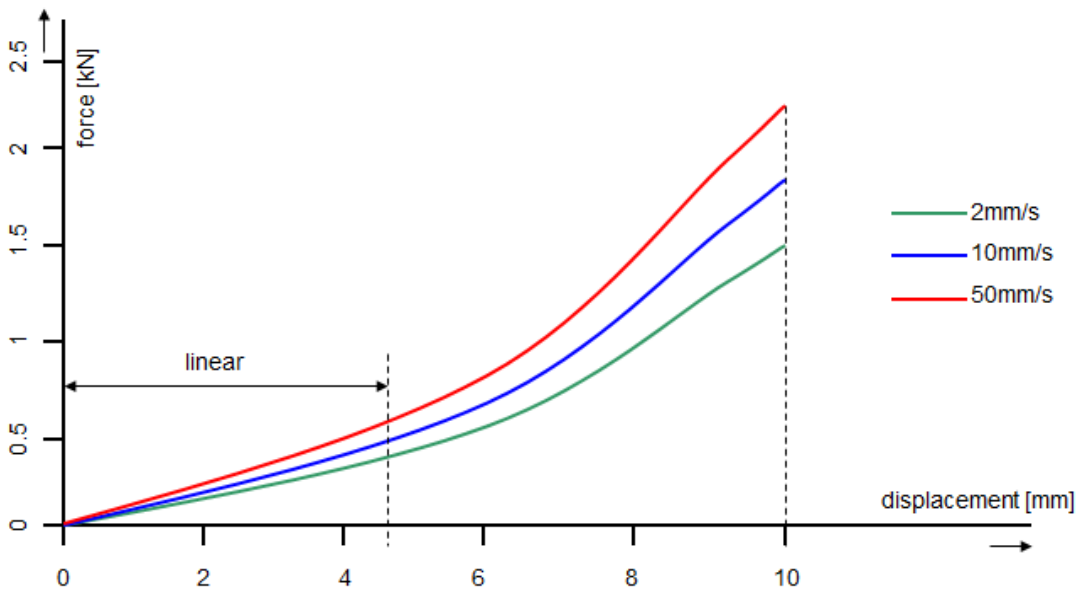
time [s]	position [mm]	force [kN]
0,00	0,07	0,09
0,05	0,13	0,10
0,10	0,15	0,11
0,15	0,26	0,11
0,20	0,31	0,12

Practical data processing:

- The Inova equipment used in this experiment creates a data file in the above format. The only slight problem is the column separator, where a space is used instead of the standard tab and the decimal separator is a dot. This must be set in the input formatting of the retrieved data:



- For processing of the data on the dependence of the force on the compression, the time column is redundant. The required dependence is obtained from the columns with values of compression and force. An X-Y graph will be created from these values, with compression on the horizontal axis and force on the vertical axis.
- The slope of the displayed curve expresses the stiffness value, from its progress it can be concluded whether the dependence is linear, partially linear, etc.
- To compare the effect of the speed, the data from measurements of the three speeds can be merged into one graph - resulting in a graph with three compression curves for three different speeds.
- It can be concluded from the displayed curves whether the stiffness depends on the speed (if so, the curves will be different, otherwise they will be on top of each other).



Presenting the results:

The results should be presented clearly and briefly. It is therefore unnecessary to publish the contents of the data files, i.e. the "infinite" table of numbers. Therefore, the following is sufficient to clearly present the results of this experiment:

- A graph of force dependencies - displacement for three compression speeds (see above)
- simple table with stiffness values for 3 speeds in the linear part of the dependence

speed [mm/s]	stiffness [N/mm]	from
2	110	0-6 mm
10	130	0-5 mm
50	150	0-4 mm

- assessment of linearity of the progress, i.e., for example from 0 to “some value” linear, therefrom non-linear
- evaluation of the effect of the compression speed on the stiffness of the rubber bushing

Task 2: Tensile test of a steel specimen

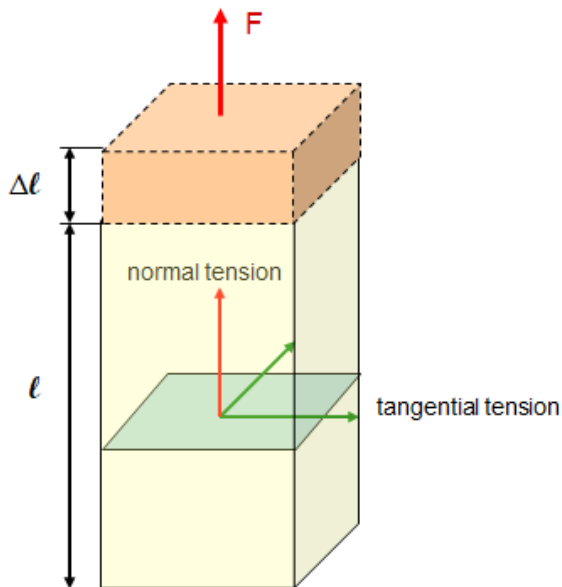
1. Task

- Measure the dependence of normal stress σ on the relative elongation ϵ of the specimen.
- Create a graphical representation of the measured dependence.
- Evaluate the following material properties of the sample from the measured data:
 - Young's modulus of elasticity E
 - yield strength R_e (if possible)
 - breaking strength R_m

2. Theoretical analysis of the experiment

Definition of physical quantities:

Mechanical stress is a condition that occurs in a body due to outside forces. The stress actually indicates the internal distribution of forces per unit area. The force vector acting on each imaginary surface of a body can be expressed in a system of coordinates formed by three mutually perpendicular axes. Two axes are in the plane of the surface and the third is perpendicular to the plane. Forces affecting the plane are expressed by tangential stress, the force perpendicular to the plane by normal stress.



For the force stressing the specimen in the direction of its axis, the normal stress σ [Pa] can be defined by the equation:

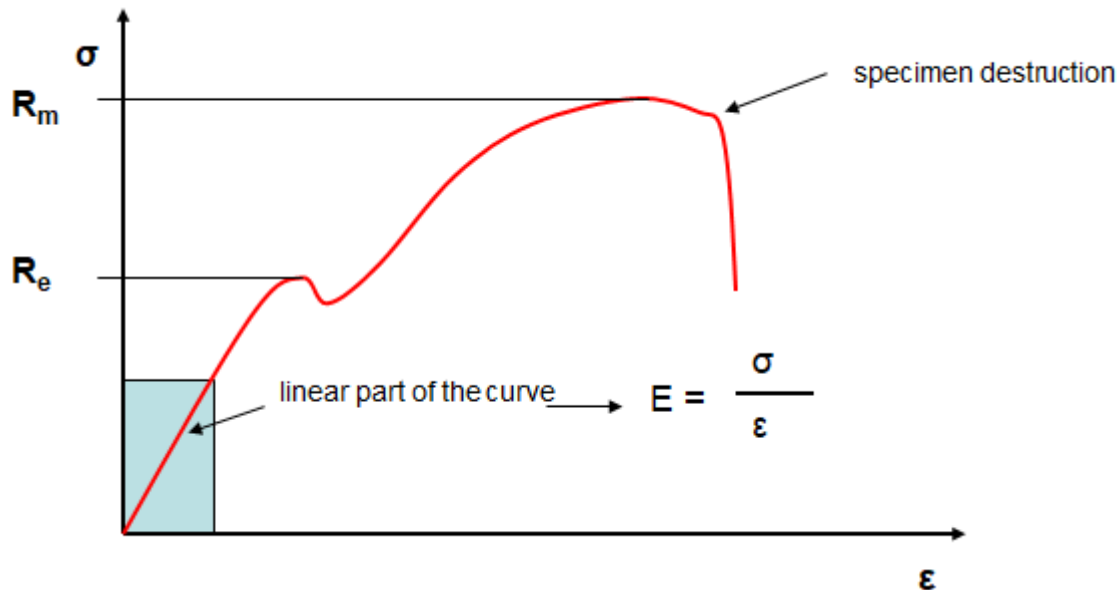
$$\sigma = \frac{F}{S} \quad \text{where } F \text{ is the force acting in the direction of the axis [N]} \\ S \text{ is the area of the sample perpendicular to the axis [m}^2\text{]}$$

The stressing force causes elongation of the specimen. This is expressed as relative elongation ϵ

$$\epsilon = \frac{\Delta l}{l} \quad \text{where } \Delta l \text{ is the elongation of the specimen [m]} \\ l \text{ is the original length of the specimen [m]}$$

The dependence of the normal stress σ on the relative elongation ϵ is expressed graphically and other material properties can be derived from the shape of this dependence:

- Young's elasticity modulus E [Pa] in the linear part of the curve as the ratio σ to ϵ
- yield strength R_e as the first local maximum of σ
- breaking strength R_m as the absolute maximum of σ .



Equipment needed for the experiment:

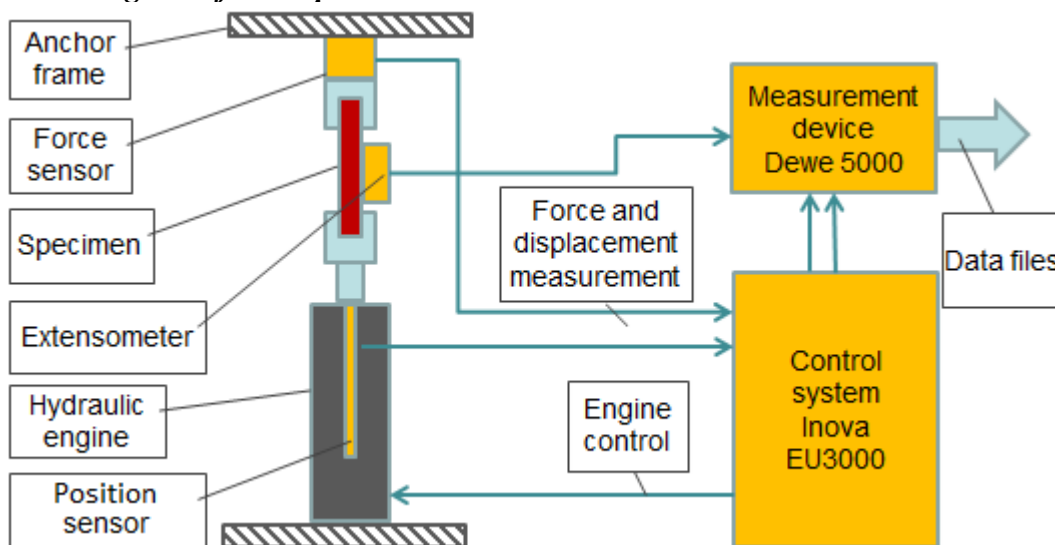
- Equipment for measuring the initial dimensions of the specimen
- Device for mechanical stretching of the specimen with jaws suitable for anchoring of the sample
- System for measuring and recording the progress of the required values - relative elongation of the specimen ϵ , the force F and displacement of jaw (for inspection only)
 - o Extensometer
 - o Force sensor
 - o Jaw position sensor
- System for processing of the results - data files
 - o PC and SW (matlab or spreadsheet editor, e.g. Excel, Calc)

3. The actual experiment procedure

Equipment used:

- Digital caliper
- Inova FU 250 testing machine
- Jaw displacement sensor integrated in the testing machine
- Force sensor integrated in the testing machine
- Extensometer
- Inova EU 3000 control system to the testing machine control and the jaw displacement and the force measuring
- Dewe 5000 measurement device for measuring the signal from the extensometer, taking signals of the displacement and the force sensors and recording the data

Block diagram of the experiment:



Preparation of the experiment:

The Inova control system is used to start-up the hydraulic motor. The experiment requires:

- Programming the displacement of the hydraulic engine according to the requirements

The Dewe 5000 system is used to record the data. The experiment requires:

- To set the measurement and recording parameters of the displacement, elongation and force
- To define the mathematical channels to calculate σ and ϵ

Experiment procedure:

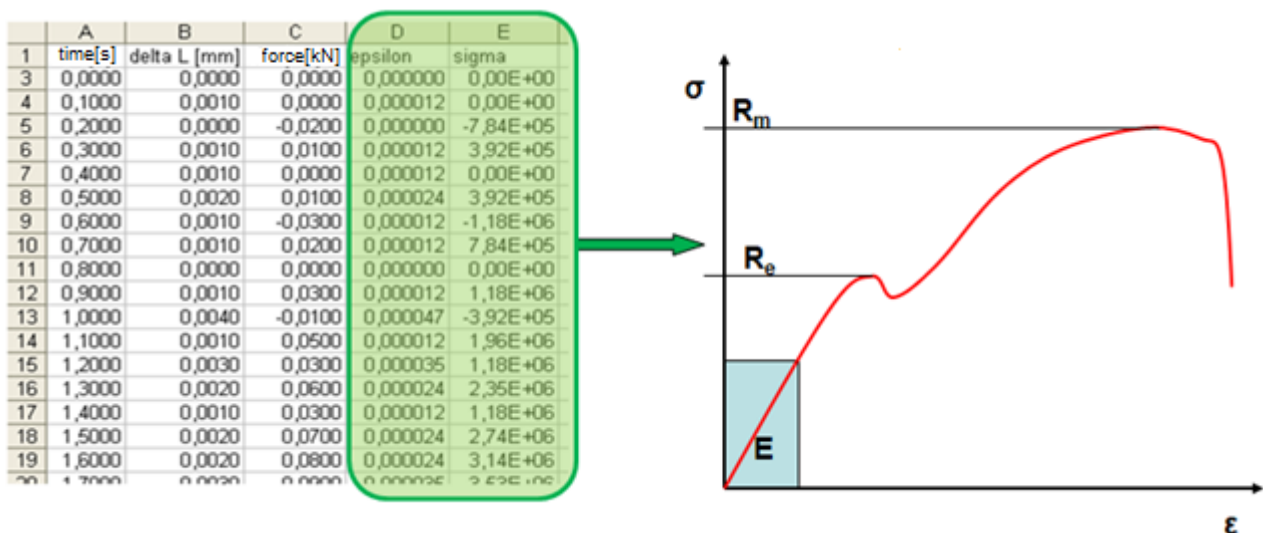
- Measuring the initial dimensions of the specimen
- Installing the extensometer to the specimen
- Inserting the specimen into the testing machine
- Setting the initial dimensions on the measuring device
- Starting the loading process of the specimen while recording the data

4. Processing the measured data and presenting the results

Practical data processing:

The Dewe 5000 measuring system creates binary data files when measuring. After the measuring, they must be exported into generally readable files. The resulting files are in standard form, no special formatting of the input is needed.

- In addition to the time axis, the files contain a record on the progress of the elongation Δl and loading force F . The values σ and ε are calculated in the other columns of the files
- Columns σ and ε are used to process the results, and the dependence of σ on ε is graphically displayed based on data from these columns.
- From the displayed curve $\sigma - \varepsilon$ the following can be determined:
 - o Young's modulus E as the slope of the initial linear part of the curve
 - o yield strength R_e as the first local maximum of σ
 - o breaking strength R_m as the absolute maximum of σ



Presenting the results:

- Graph of dependence σ on ε
- Read values E , R_e and R_m
- Evaluate whether the measured data matches the expected table values

Task 3: Measurement of a liquid damper characteristic

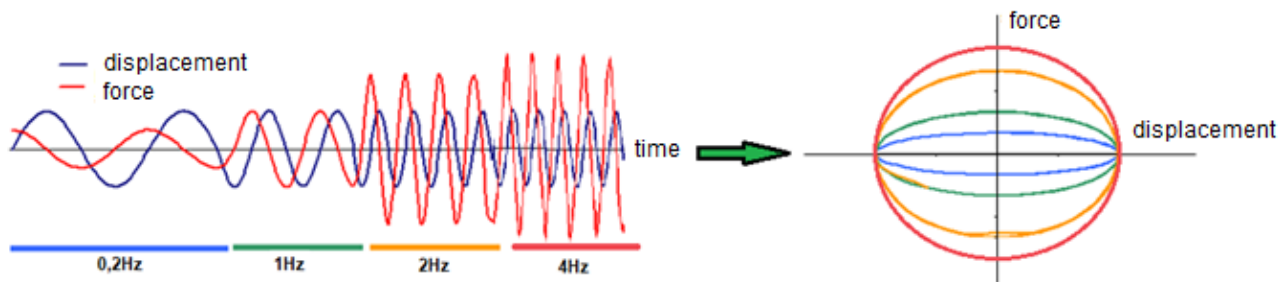
1. Task

- Measure the dependence of the force on the displacement of a liquid damper for four frequencies of harmonic movement– 0.2 Hz, 1 Hz, 2 Hz and 4 Hz.
- Create a graphical representation of the measured dependence.
- From the measured characteristics calculate the maximum tensile and compression forces of the damper for each frequency. Display the calculated values in the table and draw the dependence force - frequency graph.
- Based on the measured values evaluate whether the damper is functioning correctly.

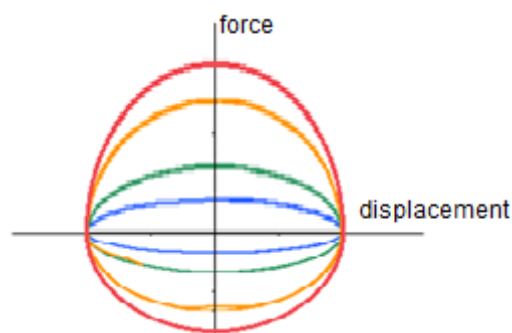
2. Theoretical analysis of the experiment

Description of a liquid damper

At present, liquid damper is the most commonly used type of damper. Its working mechanism is liquid flowing through a hole in the damper's piston. The amount of liquid flowing through the hole per time unit is determined by the cross-section of the hole, the properties of the liquid and the pressure of the liquid. The pressure is exerted by an external force acting on the piston of the damper. If we assume that everything is constant except for the pressure, it can be derived that the force exerted by the damper is proportional to the speed of the piston movement.

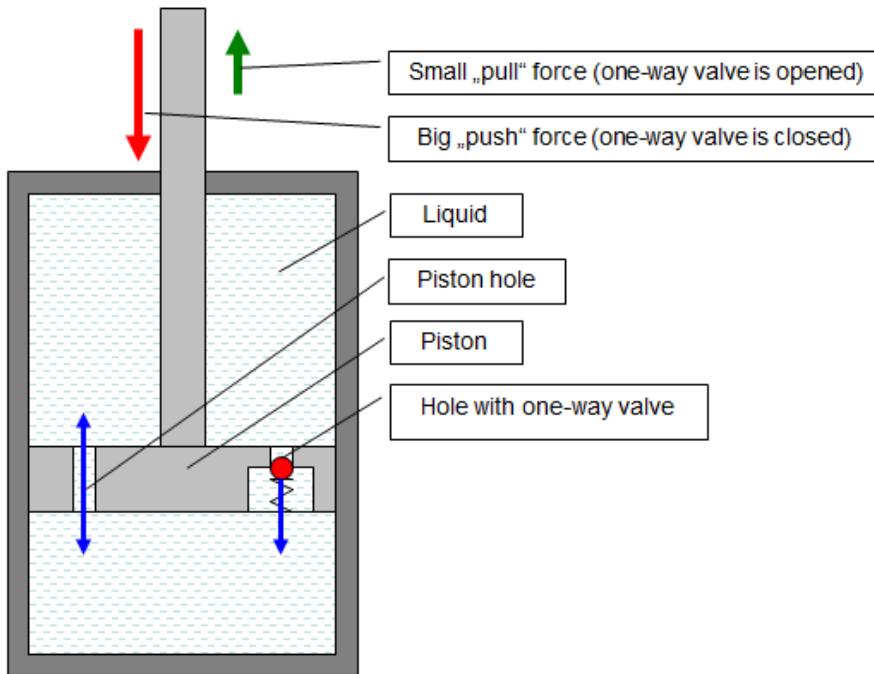


In some cases, various damping forces are needed to compress and tensile the piston. This is typical for dampers from actively suspended car seats. When the car seat moves downwards, the weight of the driver moves in the direction of gravity, when the seat moves upwards, the weight of the driver moves against the direction of gravity. Therefore, the upwards and downwards damping forces must be different. The graph of the dependence of the force on the shift is asymmetric according to the

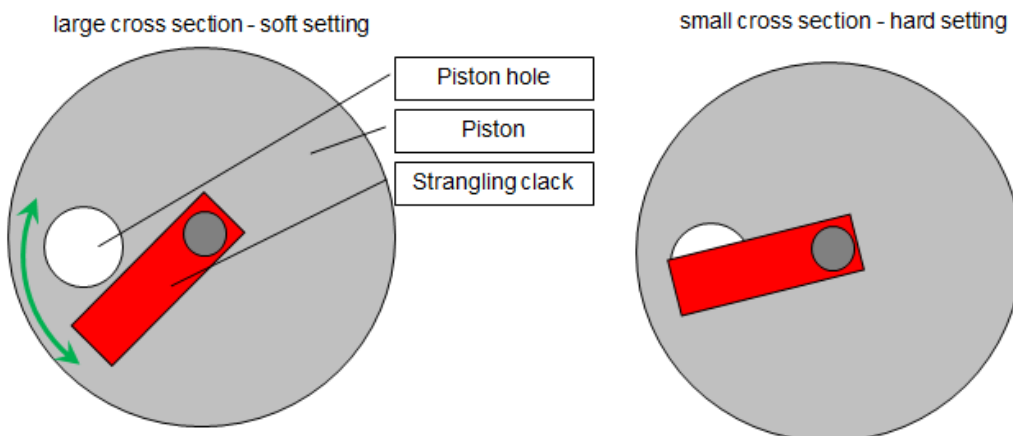


axis X, the forces in one half plane are higher than forces in the other half plane.

Moreover, the liquid damper has a hole with a one-way valve in the piston. This achieves a different total cross-section of the holes for each direction of piston movement. In one direction of piston movement the one-way valve is closed and the liquid flows only through one hole, in the second direction of the movement the valve is open and the liquid flows through both holes. The force for both directions of movement is different.



If the progress of the dependence of the force on the speed must be continuously adjusted; the cross-section of the hole can be changed by a strangling clack. This method is used, for example, to change the comfort setting on actively suspended driver seats, the driver can simply set the stiffness of the damper and the whole seat himself.



Recently, this mechanical method has been replaced by a change in the properties (density) of the liquid. A special liquid with magnetic properties (magnetoreological liquid) is used, the density of which is influenced by the electromagnetic field. This method allows very fast changes of the properties. It is also used, for example, in the so-called active suspension in a car, where the spring-damper unit responds to the driving style and road character.

Equipment needed for the experiment:

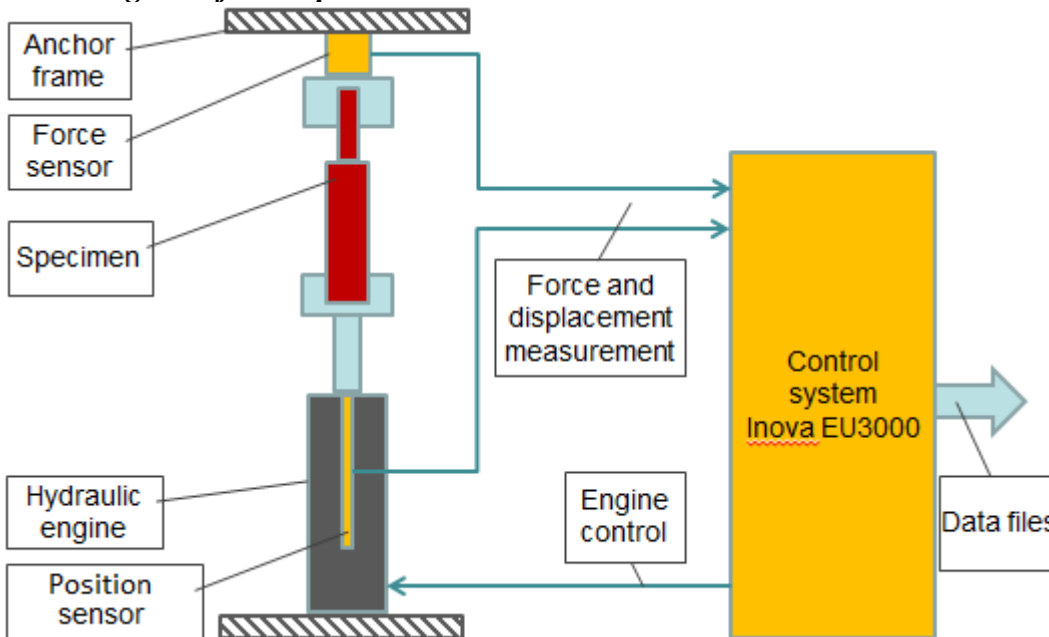
- Equipment for mechanically loading the damper with a harmonic signal with different frequencies
- System for measuring and recording the progress of the required values - displacement and the force
 - o Damper piston displacement sensor
 - o Force sensor
- System for processing the results - data files
 - o PC and SW (matlab or spreadsheet editor, e.g. Excel, Calc)

3. The actual experiment procedure

Equipment used:

- Hydraulic engine Inova AH 25-250 (max.: 25kN, 250mm, 1m/s)
- Anchoring frame
- Inova EU 3000 control system to the hydraulic engine control and data measuring and recording
- Position sensor integrated in the hydraulic engine
- Force sensor GTM 10kN

Block diagram of the experiment:



Preparation of the experiment:

The Inova control system is used to start-up the hydraulic motor and record data. The experiment requires:

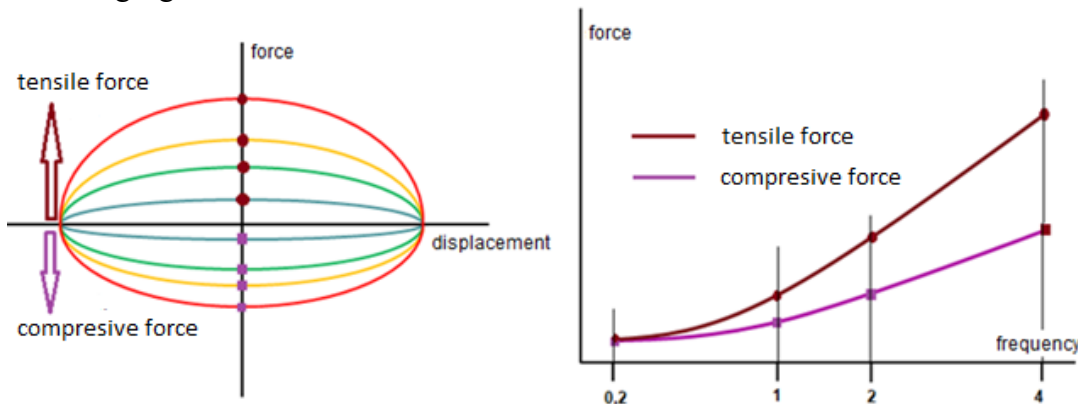
- Programming the displacement of the hydraulic engine according to the requirements
- To set the measuring and recording parameters of displacement and force

Experiment procedure:

- Clamping the damper to the loading machine
- Excitation of the damper by a harmonic signal
 - o Identical amplitude 15 mm (according to the stroke of the measured damper)
 - o Frequency gradually 0.2 Hz, 1 Hz, 2 Hz and 4 Hz, several periods (7) for each frequency to eliminate transient states when starting and stopping
- Record of the displacement and the force for all excitation frequencies

4. Processing the measured data and presenting the results

An X-Y graph is created from measured displacement and force data as the dependence of the force on the displacement. Data from the four excitation frequencies is transferred to a common graph, creating a separate curve for each frequency. The result will be similar to the graph on the left in the following figure.



Due to the polarity of the signals on the loading machine, positive values are tensile and negative are compressive. The maximum and minimum curve values in the direction of axis Y are the value of the tensile and compressive force for the determined frequency (i.e. for the maximum movement speed at the required frequency). The values of maximum force for all frequencies are read from the upper half plane of the graph, so the tensile load forces of the damper are obtained. Similarly, the values of minimum force for all frequencies are read from the lower half plane, the compressive load forces of the damper are therefore obtained after conversion into the absolute value.

The results can be entered into the table as follows:

frequency [Hz]	0.2	1	2	4
tensile force [kN]	0.62	1.26	2.3	3.71
compressive force [kN]	0.35	0.86	1.9	2.8

The obtained values from the above table can also be processed graphically, the right graph in the previous Fig is an example of such result. On the horizontal axis is the frequency, on the vertical axis is the force. The graph has two curves, one for the tensile force and the other for the compressive force of the damper (the absolute value of the force is used so that both curves are in the same half plane)

The correct function of the damper can be evaluated from the X-Y graph of the dependence force - displacement. Regular curves indicate a good damper, diverse irregularities and non-linearities reveal a malfunction of the damper. There is a typical delay in the force of a damper on change of the movement direction of the piston rod (i.e. when passing through the horizontal axis). In part of the displacement, the damper actually does not create the required force.

This is usually caused by

- incorrect function of the valves in the piston rod holes, which do not “manage” to close in time when the movement direction of the damper piston changes
- loss of a part of the liquid damper filler or air bubbles in the damper liquid



In the conclusion it can be evaluated whether the damper has different characteristics (various forces) for both movement directions, whether the dependence of forces on frequency is linear and whether the damper is functioning correctly or whether it is defective.

Task 4: Vibration Frequency Analysis

1. Task

- Determine the frequency spectrum of the rotary hammer vibrations.
- Graphically display the measured amplitude frequency spectrum.
- For comparing, also display the power spectral density of the measured vibrations.
- From the graph, subtract and report the frequencies of the most significant vibrations in a table.

2. Theoretical analysis of the experiment

Frequency spectrum of vibrations

The vibrations frequency spectrum shows on which frequencies the monitored equipment oscillates. With hand tools, this is important for determining the load on the human body. Similarly, it is necessary to know the vibrations frequency spectrum during any other interaction of human with the equipment (e.g. car drivers) The human body is more sensitive to some frequencies than others, therefore, it is necessary to know the frequency loads for determining the maximum possible exposure to vibrations.

Fourier transform of measured signal of vibration is used for the frequency analysis of signals.

Laplace and Fourier transforms

Pierre-Simon Laplace (1749-1827) was a French mathematician, physicist and astronomer.

Jean Baptiste Joseph Fourier (1768 - 1830) was a French mathematician and physicist.

For a continuous function $f(t)$ defined in the interval $-\infty, \infty$, the Laplace transform $L(p)$ is defined as follows:

$$L(p) = \int_{-\infty}^{\infty} f(t)e^{-pt} dt$$

In technical practice, the Fourier transform is often used instead of the general Laplace transform. It is defined in the same way, only the general complex operator of the Laplace transform p is replaced by the relation $j\omega$, where ω is the angular frequency ($\omega = 2\pi f$):

$$F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-j\omega t} dt$$

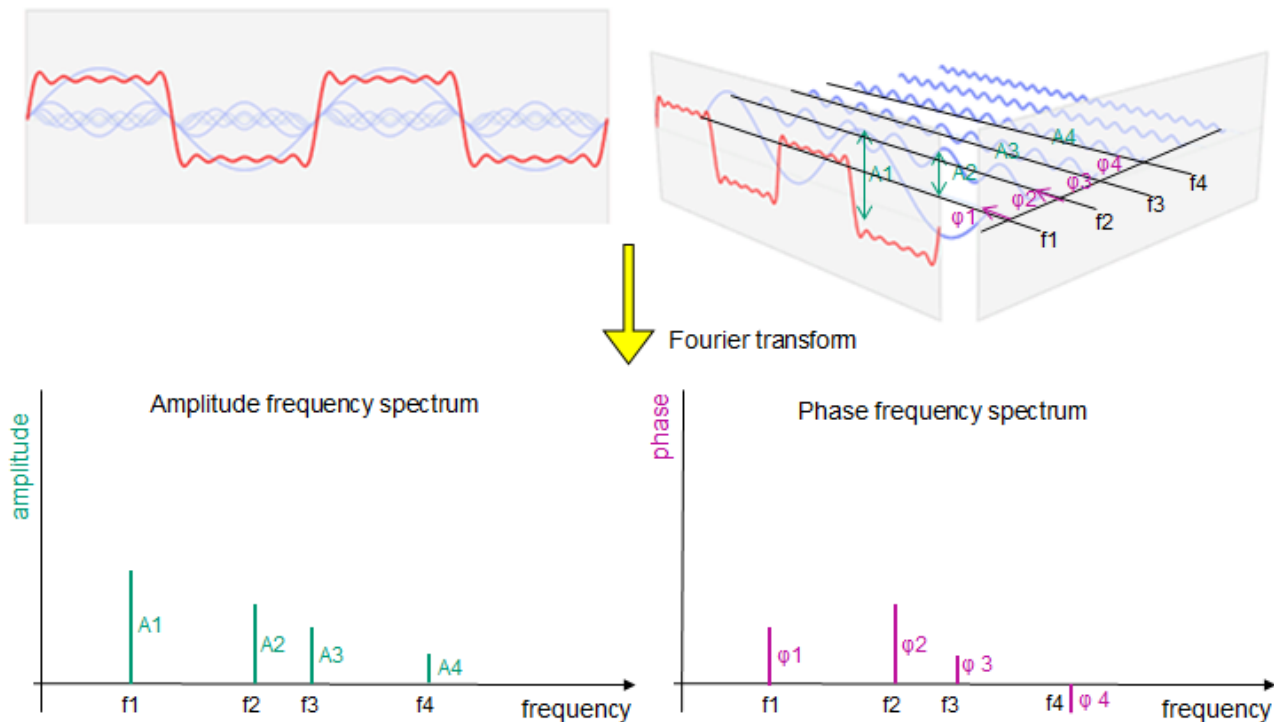
By introducing the angular frequency ω instead of the general operator p , the Fourier transform transforms the function from time dependent to frequency-dependent expression.

In fact, the Fourier transform “decomposes” the original function into simple harmonic signals (sine waves) with different amplitudes, frequencies and phases. If it is graphically displayed which sinusoids the original function consists of in dependence on frequency, the result is the frequency spectrum of the function. For greater clarity, the dependence of amplitudes and the dependence of phase shift on frequency are shown separately. This results in an amplitude frequency spectrum and a phase frequency spectrum.

In many cases the phase is not important and only the amplitude spectrum is interpreted as a result. This will also apply in this case. To evaluate the effects of vibrations on a human, the value of vibrations on individual frequencies is important, it does not depend on the phase (i.e. the time delay of individual elements).

The principle of Fourier transform is shown in the following figure:

The red function can be decomposed to series of sine curves with various frequencies, amplitudes and phases.



Practical Fourier transform calculation

Fourier transform was originally defined for the continuous function $f(t)$ and the calculation was carried out according to the above formula. Whenever vibrations of some equipment are measured, the result is never a continuous function of these vibrations. Each contemporary measuring device contains an A/D converter, which turns the originally continuous vibration sequence into a sequence of discrete samples and therefore the original Fourier transform cannot be used for the calculation. For these cases, the formula of the Fourier transform for numerical sequence must be used.

$$S(\omega) = \sum_{k=-\infty}^{\infty} s(k)e^{-j\omega k}$$

This formula must be modified because the result of measuring is not an infinite number of samples. Only some final number of samples N is available and the resulting formula for calculating the discrete Fourier transform (DFT) is:

$$D(n) = \sum_{k=0}^{N-1} (k)e^{-j2\pi\frac{kn}{N}}, \quad n = 0, 1, \dots, N - 1$$

Calculating this equation takes quite a long time but in 1965 J.W. Cooley and J.W. Tukey described a very effective algorithm for calculating DFT.

This algorithm for calculating DFT is called (**FFT - Fast Fourier Transform**) and allows DFT to be calculated in real time. In real time, the resulting amplitude transfer function can be seen on the measuring device and from its peak (peaks) it is possible to immediately read the value of the vibration frequencies of the tested part.

For the correct function of the FFT calculation, the sampling frequency by which the signal of the measured oscillation of the part is sampled is important. According to Shannon's theorem, the sampling frequency must always be greater than twice the maximum signal frequency:

$$f_{\text{sampling}} > 2 * f_{\text{max}}$$

If we look at it in another (and slightly simplified) way, it can be said that FFT will calculate the frequency spectrum for us up to half of the selected sampling frequency. It must therefore always be at least twice the maximum expected frequency of the oscillation of the tested part.

Power spectrum, power spectral density

In the technical practice of frequency analysis of vibrations, you can encounter the terms **frequency power spectrum** and **power spectral density**, shortly PSD. The frequency power spectrum shows practically the same as FFT, but due to the fact that it works with power, the obtained spectrum is "purified" from energetically insignificant components of oscillations. The power spectral density then determines the distribution of the power spectrum according to the signal frequencies. The amplitude of the power spectrum is thus divided by the value of the corresponding frequency, thus obtaining a "distribution" of the power spectrum according to the frequency band of the signal.

Because it is difficult to measure the vibration power of a test part, a simplistic quadratic relationship between the power and the measured vibration amplitude signal is very often used to calculate the power spectrum. Thus, the same measured oscillation signal of the part is used, but its square is used to calculate the frequency power spectrum or PSD.

Vibration sensors

Vibrations can be measured by various sensors. The first possibility is to directly measure the route of the oscillation of the part, i.e. in fact the displacement of the part by a position sensor. In this case, contact-free sensors for measuring the route are used mostly based on laser technology. The disadvantage of this is the necessity to have a "fix point" for installation of the sensor. A place that is fixed and does not vibrate. In practice, it is often an insoluble requirement to find a "firm" location for installing the sensor and, moreover, so that the laser "sees" the object being measured, it is often impossible. At the same time, for higher frequencies, a fast laser sensor is needed which is very expensive. Therefore, accelerometers are exclusively used for measuring vibrations. They measure up to high frequencies without problems at an acceptable price. Their biggest advantage is that they do not need to be installed on a fix point - they are installed directly on the vibrating object. So, the route of the oscillation of the part is not measured but the acceleration which, as far as frequencies contained in vibrations are concerned, is the same.

Equipment needed for the experiment

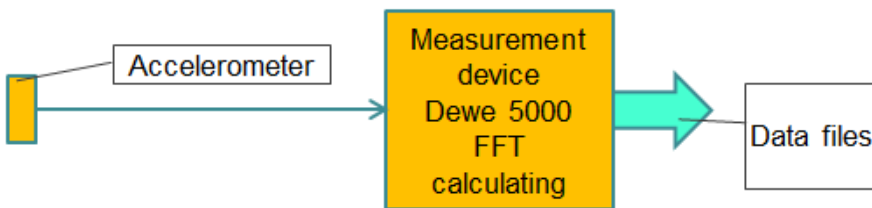
- System for measuring and recording the vibrations signal with the possibility of calculating FFT.
 - o Tested part vibration sensor - accelerometer
- System for processing the results - data files
 - o PC and SW (matlab or spreadsheet editor, e.g. Excel, Calc)

3. The actual experiment procedure

Equipment used:

- DEWE5000 measurement device
- Techlab 50G accelerometer

Block diagram of the experiment:



Preparation of the experiment

The Dewe 5000 device is used to record the data. The experiment requires:

- To set the measuring and recording parameters of the signal from the accelerometer
- To define the mathematical channels for calculating FFT and PSD from the measured signal

Experiment procedure:

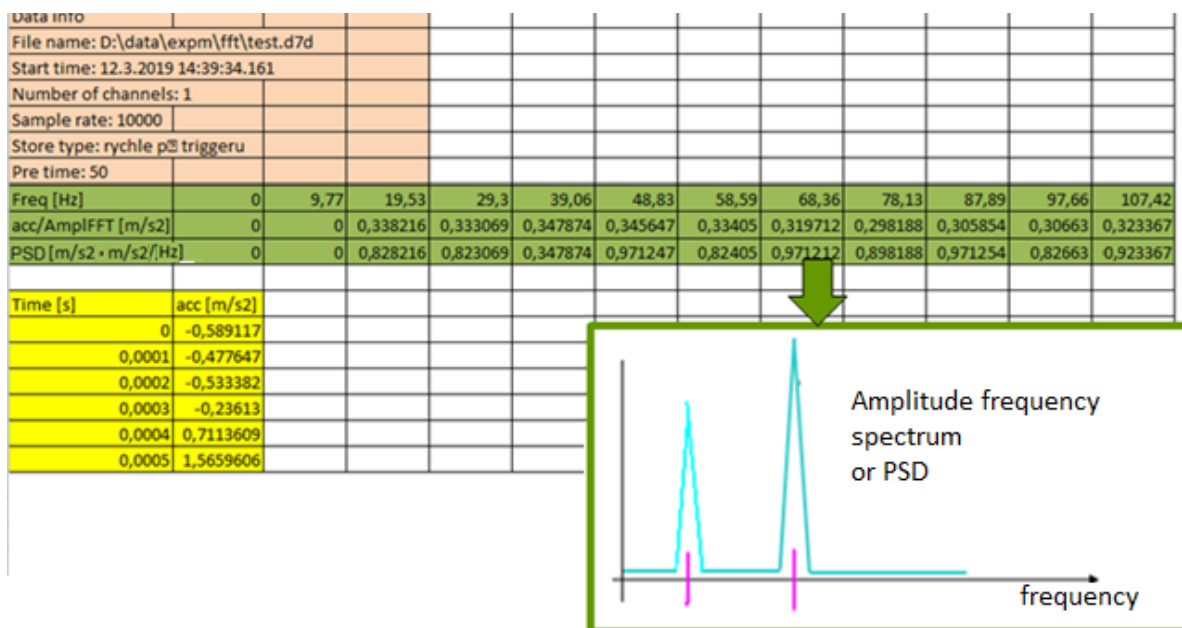
- Installing the accelerometer on the tested part
- Start recording, start the device, measure the vibration

4. Processing the measured data and presenting the results

This time the exported data has a slightly unusual format. The time record of the oscillation, as well as the calculated FFT and PSD is stored in one file.

At the beginning of the file, there is a header (here highlighted in pink), then there are lines with the record of the FFT and PSD (here highlighted in green), then two columns with the time record of the oscillation (here highlighted in yellow).

The main output of the experiment, i.e. amplitude frequency spectrum of vibrations is obtained by plotting the X -Y graph from the two rows of the FFT record (here in green). On the X axis there will be the first row - frequency, on the Y axis there will be the second row, i.e. amplitude. Similarly, a power spectral density graph can be obtained from the frequency and PSD lines:



Frequency values with the maximum amplitude can be read from the displayed spectrum. They are the dominant vibration frequencies of the tested part. The read values can be displayed in a table.

Task 5: Measurement of amplitude frequency transmission characteristic

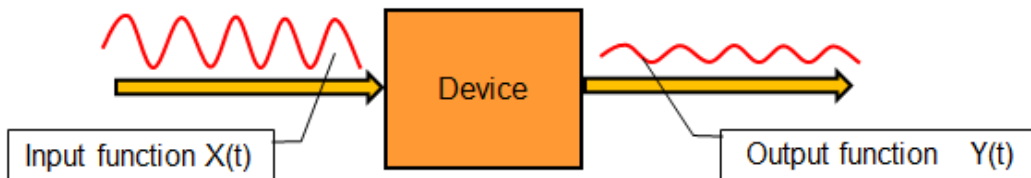
1. Task

- Measure the amplitude frequency transmission characteristic of a car seat foam filler specimen for harmonic excitation with amplitude 3 mm in the frequency band from 1 to 10Hz.
- Display the amplitude frequency transmission characteristic.
- Determine the resonance frequency of the tested foam.

2. Theoretical analysis of the experiment

Transmission characteristic

In general, transmission characteristic determines the dependence of the output function of the equipment on the input function. It is used to describe the behaviour of equipment in almost all technical fields.



The transmission characteristic is defined as the ratio of output function $Y(t)$ to the input function $X(t)$, i.e.:

$$G(t) = \frac{Y(t)}{X(t)}$$

Expressing the transmission from the time progress of functions is not very practical, therefore the ratio of images of the output and input functions obtained by Fourier transform is usually used for its expression (see task 4).

Frequency transmission characteristic

If, instead of time-dependent functions, their images obtained using Fourier transform are used, the transmission characteristic will be defined as follows:

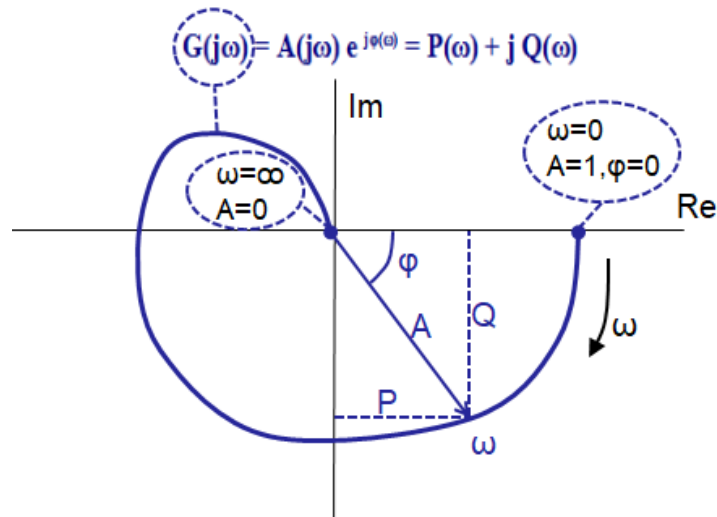
$$G(j\omega) = \frac{Y(j\omega)}{X(j\omega)}$$

After many mathematical modifications, the transmission can be expressed as:

$$G(j\omega) = A(j\omega)e^{j\varphi(\omega)} = P(\omega) + jQ(\omega)$$

This expressed transmission characteristic is called the frequency transmission characteristic. The frequency transmission characteristic describes how the input signal is changed by passing through the equipment depending on its frequency.

It is a complex function that can be directly displayed in the complex plane.



Displaying the frequency characteristic in the complex plane provides a self-contained summary of the progress of the transmission depending on the frequency of the signal.

In many cases, however, for a more comprehensible presentation, the representation in the complex plane is omitted and the expression of the transmission function is divided into separate expression of amplitude and phase on frequency:

$$A(\omega) = \sqrt{P^2(\omega) + Q^2(\omega)} \qquad \varphi(\omega) = \arctan \frac{Q(\omega)}{P(\omega)}$$

Thus, the **amplitude frequency transmission characteristic** and the **phase frequency transmission characteristic** are created. So, the amplitude characteristic determines how the ratio of the amplitude of the output and input signal changes depending on the frequency and the phase characteristic states which is the phase delay of the output signal to the input signal. Both are expressed by a traditional graph:



In some cases, to describe the behaviour of the system, it is sufficient to display only the amplitude frequency transmission characteristic.

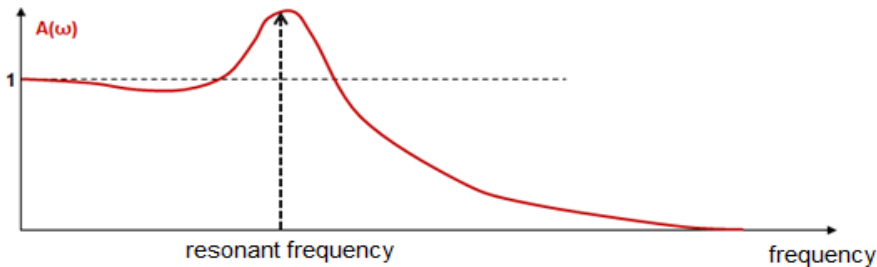
Amplitude frequency transmission characteristic and resonance frequency

Thus, if the amplitude frequency transmission characteristic indicates the ratio of the amplitudes of the output to the input signal, it is apparent that if:

- $A(\omega) = 1$ the output signal is equal to the input signal and the equipment does not affect the input signal
- $A(\omega) < 1$ the output signal is lower than the input signal and the signal in the equipment is therefore damped
- $A(\omega) > 1$ the output signal is higher than the input signal and the equipment amplifies the input signal

Thus, the behaviour of the mechanical part during excitation by the signal at various frequencies can be expressed using the amplitude frequency transmission characteristic. Then it is clear for which frequencies the part damps oscillations ($A(\omega) < 1$), and when on the contrary there is higher oscillation of parts than the excitation signal ($A(\omega) > 1$).

Values of the amplitude frequency transmission characteristic greater than 1 show that the part oscillates with greater amplitude than the amplitude of the excitation signal and this state is typical for excitation on its resonance frequency.

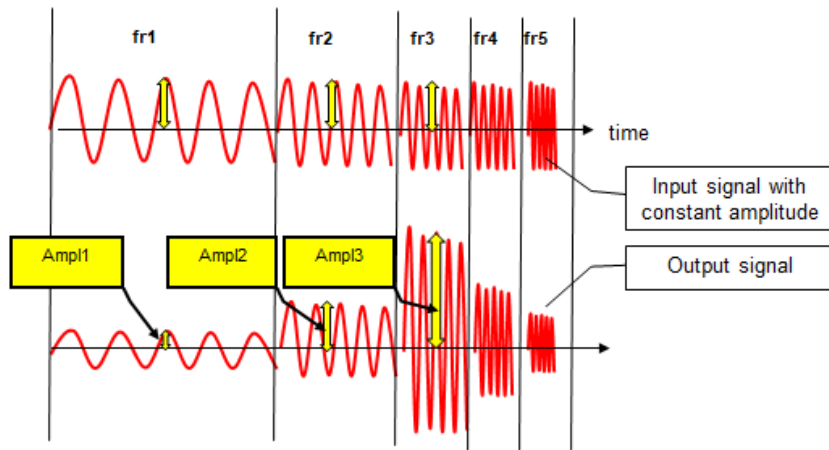


Principle of measuring the amplitude frequency characteristic of the seat filling foam:

For the description of the seat filling foam only the amplitude frequency characteristic is used. How the foam and the all seat damp the value of vibrations is important. The phase delay does not matter and, therefore, to express the phase characteristic is not necessary.

When developing new types of foams, only filler foam specimens are tested for simplicity and cheaper testing. Only after the new properties of the foam are found, the whole seat is tested.

The foam specimen is placed on the vibration equipment and a mass is placed on the foam (corresponding to the load by a human body according to the ratio of the area of the specimen and the whole seat). The vibration device will oscillate by the harmonic signal with constant amplitude and gradually increasing frequency (change of the frequency by jumps or fluently) within the required range. During the excitation, the amplitude of the input excitation signal and the amplitude of the oscillation of the load is measured. The amplitude frequency transmission characteristic is calculated from these signals and it is displayed. The curve peak shows the foam resonance frequency.



Equipment needed for the experiment:

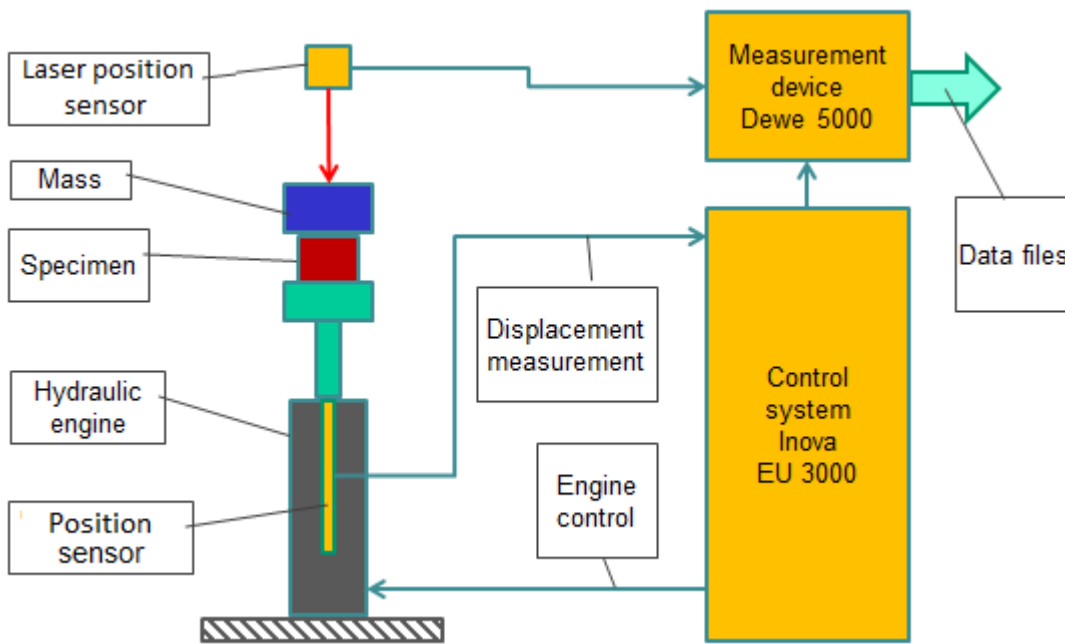
- Harmonic signal excitation device with a variable frequency.
- Mass to load on the measured foam.
- System for measuring and recording of the required values - input harmonic signal and output (the load mass on the foam) vibration signal.
 - o Sensor for input oscillation measurement.
 - o Sensor for output (the load mass on the foam) oscillation measurement.
- System for processing the results - data files
 - o PC and SW (matlab or spreadsheet editor, e.g. Excel, Calc)

3. The actual experiment procedure

Equipment used:

- Hydraulic engine Inova AH 25-250 (max.: 25kN, 250mm, 1m/s)
- Anchoring frame with linear guide and load mass
- Inova EU 3000 control system to control the hydraulic engine and data measuring and recording
- Position sensor integrated in the hydraulic engine
- Position laser sensor for monitoring movement of mass placed on the tested foam
- DEWE 5000 measuring device

Block diagram of the experiment:



Preparation of the experiment:

The Inova control system is used for the hydraulic engine control. The experiment requires:

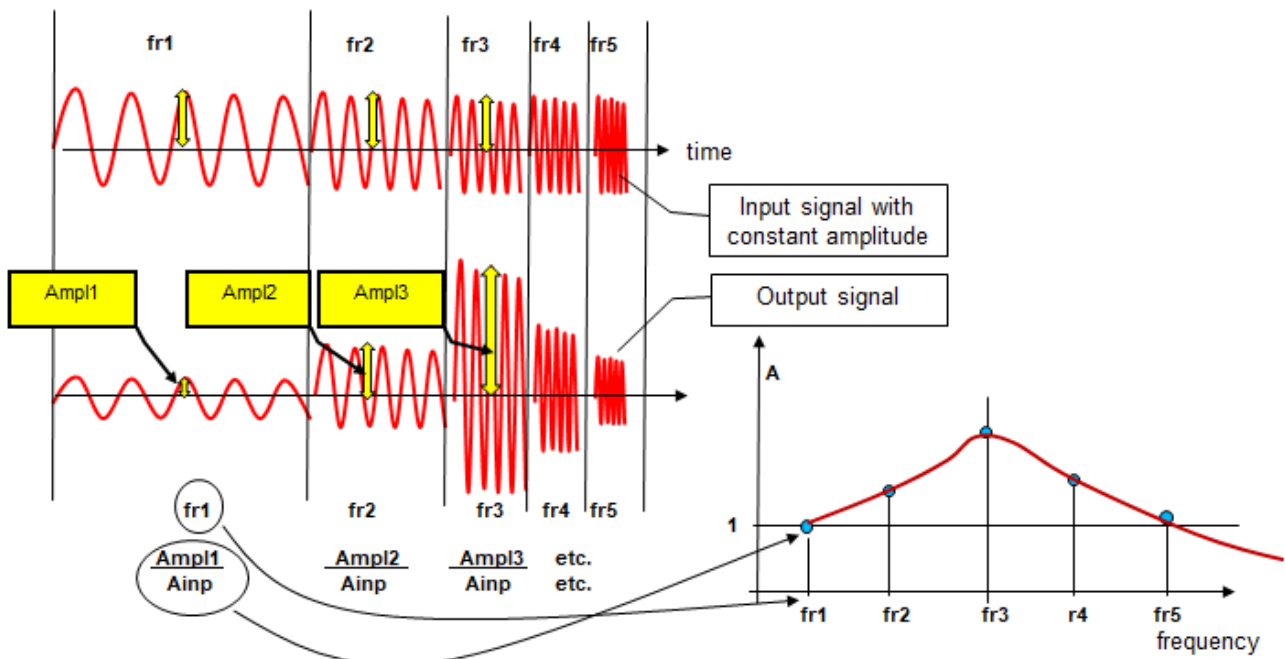
- Programming the displacement of the hydraulic engine according to the requirements

The Dewe 5000 device is used to record the data. The experiment requires:

- To set the measuring and recording parameters of the load mass displacement and the hydraulic engine displacement
- Define two mathematical channels for detecting the amplitude of the input and output signals
- Define the mathematical channel for detecting the frequency of the input signal
- Define the mathematical channel for calculating the amplitude transmission characteristic

Experiment procedure:

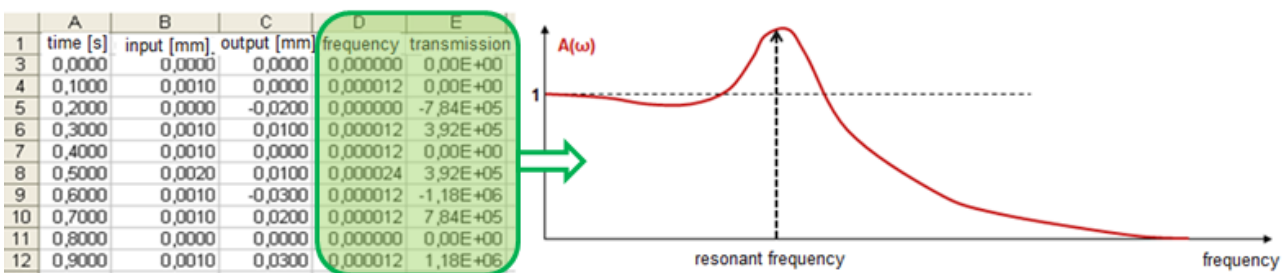
- Placing the foam specimen in the loading device and loading it with the respective mass
- Harmonic signal excitation with constant amplitude and variable frequency according to the task
- Recording the excitation signal and oscillation of the load mass, detecting amplitudes and calculating the amplitude transmission characteristic
- Releasing and removing the foam specimen



4. Processing the measured data and presenting the results

The Dewe 5000 measuring device creates binary data files when measuring. After the measuring, they must be exported into generally readable files. The resulting files are in standard format, no special input formatting is needed.

The data file contains the column with the frequency and the column with the value of the amplitude transmission. From these two columns the amplitude frequency characteristic can be graphically displayed. The frequency value in the point of the curve maximum is the resonance frequency of the tested foam.



Task 6: Measurement of the resonant frequency using the Dirac pulse method

1. Task

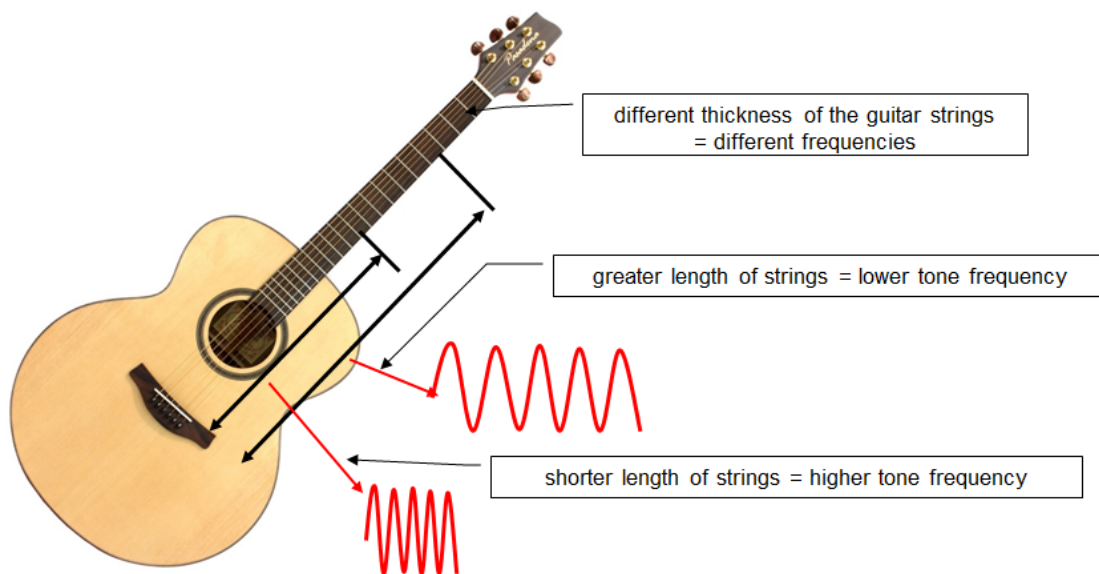
- Determine the resonant frequency of the mechanical part (or assembly) by the Dirac pulse method.
- Graphically display the measured amplitude frequency spectrum.
- Display the obtained resonant frequency in numbers.

2. Theoretical analysis of the experiment

Resonant frequency

Each physical part (or assembly of parts) reacts in some way to mechanical excitation. Generally, it can be stated that the mechanical excitation of the part will make it vibrate. Less energy is needed on some frequencies to make the part vibrate than on others, on this frequency the tendency of the part to vibrate is the highest. The frequency where vibration starts most easily or where the vibration has the highest amplitude is the resonant frequency.

The resonant frequency is determined by the shape, dimensions, material and method of the part's anchoring. A guitar string can be used as an example. After its mechanical excitation, it vibrates on a frequency - its resonant frequency. It is determined by its dimensions, i.e. thickness and length.



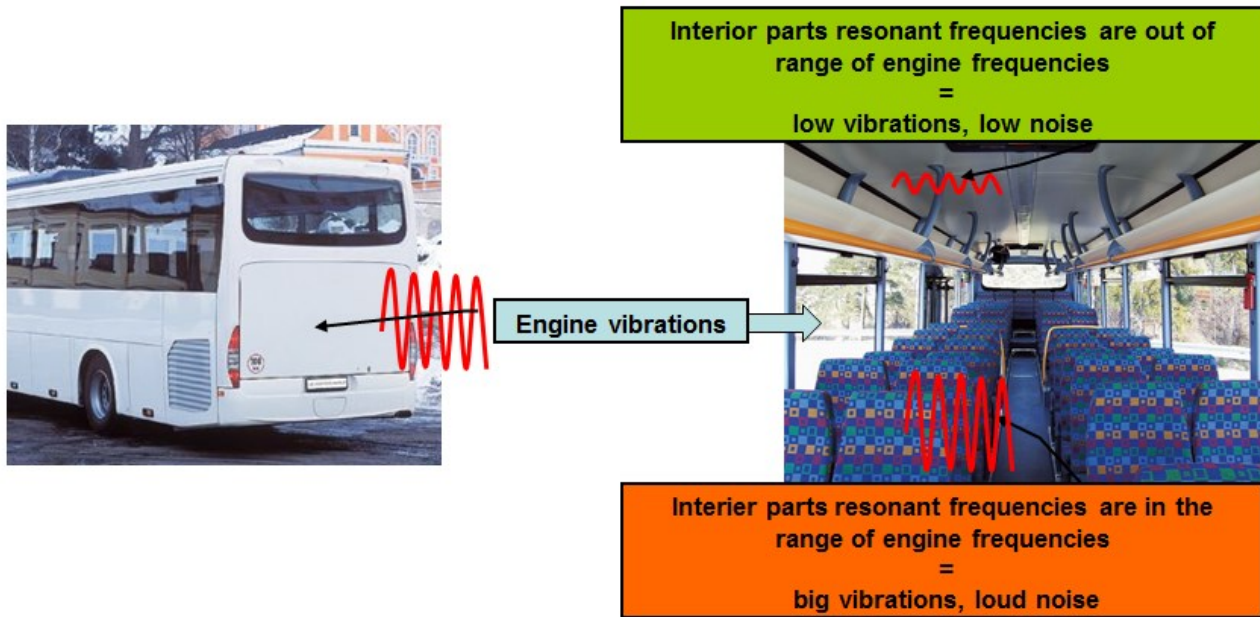
With more complex shapes of mechanical parts or assemblies of mechanical parts, there may be more than one resonant frequency. The part may be predisposed to vibrate at more frequencies thus having multiple resonant frequencies.

Determining the resonant frequency of a part again basically means determining its amplitude transmission characteristic, because it is this characteristic that displays the magnitude of the vibration amplitude as a function of frequency (see Task 5).

Resonant frequency in technical practice

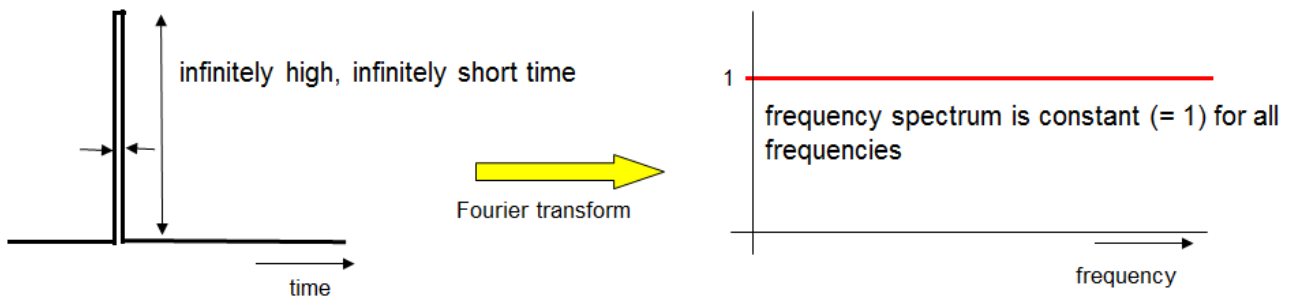
Ascertaining the resonant frequency is very important in technical practice so that during operation to avoid excessive vibration of parts due to operating vibrations. Thus, it is necessary to ensure (by proper design of dimensions, shape and material) that the resonant frequency of the device or its

parts does not lie within the range of frequencies that occur during the operation of the device. Otherwise, noise can increase, there is faster wear and in extreme cases the equipment can be destroyed due to excessive vibrations and material fatigue.



Dirac's impulse

Dirac's impulse has an **infinitely large amplitude and infinitely short duration**. The Fourier transform of the Dirac pulse is equal to one for frequencies from 0 to ∞ . It can be said that Dirac's impulse consists of an infinite number of harmonic signals with the same amplitude.



If an part is excited by Dirac's impulse, it is excited at one moment by all frequencies at the same time. As the input function for determining the frequency amplitude transmission characteristic, an infinite set of harmonic signals with the same amplitude will be used.

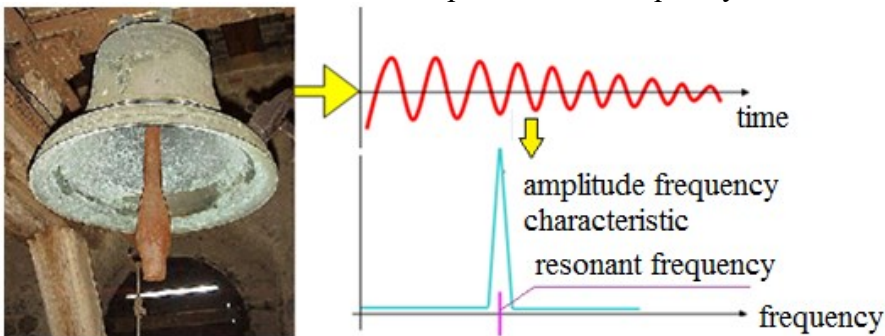
Of course, Dirac's impulse is only a theoretical mathematical definition, in practice an infinitely high and infinitely short impulse can never be produced. But a brief sharp impact gets very close. The tested part will not be excited by an infinite set of frequencies, mostly the high frequencies will be missing in the excitation. This does not matter because the actual mechanical part will not vibrate at very high frequencies. Excitation by a short sharp impact is sufficient to determine the resonant frequency.

A special hammer with a sensor is used to induce the impact, which measures the hammer's impact parameters and can therefore determine whether the excitation spectrum was wide enough.

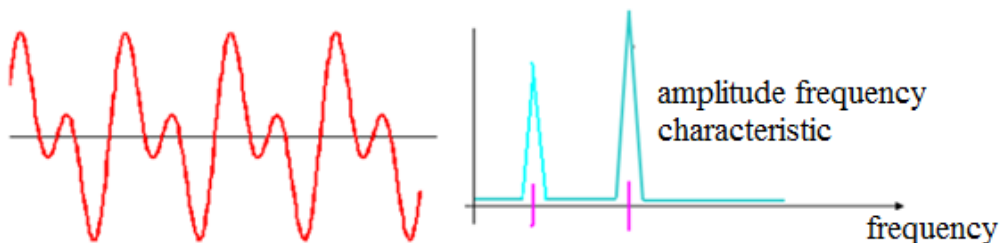


If a hammer with a sensor is not available, a normal hammer can be used, and the measuring can be repeated several times. If the measured results are identical, the excitation is OK.

If the tested part is excited by a short sharp impact, it is excited at one moment by “all” frequencies at the same time. The part vibrates on the frequency (frequencies) where it needs the minimum energy, and this is its resonance frequency. A well-known example from non-technical practice is a bell. After an impact (i.e. “Dirac’s” impulse), the bell starts to sound on its resonant frequency. This frequency does not depend on the power of the impact but on dimensions and the shape of the bell. The bell sounds (vibrates) on its resonant frequency and the amplitude frequency transmission characteristic of this vibration will peak on this frequency.



A common part with a complicated shape or a set of parts may have multiple resonant frequencies. It does not need to vibrate only with one harmonic frequency, but the vibration may consist of more harmonic signals with various amplitudes and frequencies. In this case, multiple peaks are displayed in the frequency spectrum.



Determining the resonant frequency by Dirac's impulse

The method of ascertaining the resonance frequency of a part by Dirac's impulse is based on measuring the frequency amplitude transmission characteristic of the mechanical part during its excitation by a special input function - Dirac's impulse.

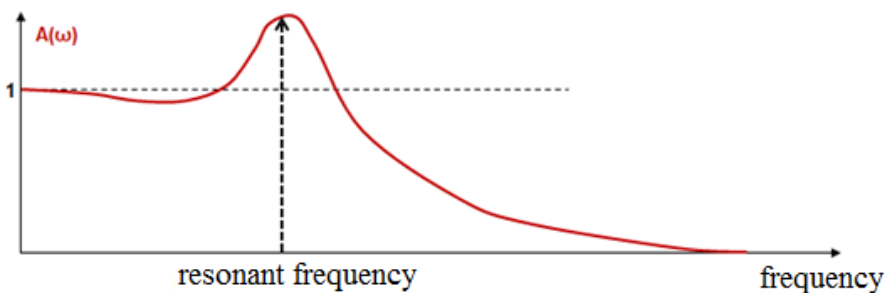
The transmission characteristic is defined as the ratio of images of input and output function, obtained by the Fourier transform of both functions (see Task 5).

$$G(j\omega) = \frac{Y(j\omega)}{X(j\omega)} = A(j\omega)e^{j\varphi(\omega)} = P(\omega) + jQ(\omega)$$

From this complex function, the frequency amplitude and phase transmission characteristic can be expressed.

$$A(\omega) = \sqrt{P^2(\omega) + Q^2(\omega)} \qquad \varphi(\omega) = \arctan \frac{Q(\omega)}{P(\omega)}$$

If Dirac's impulse is used as the input function, the input function is $X(j\omega) = 1$. The transmission characteristic is equal to the output function, i.e. directly measured vibration of the tested part. Because the phase shift is not important for the result, the transmission characteristic of the frequency amplitude is sufficient to determine the resonance frequency. This displays the value of the amplitude of the vibration depending on the frequency. The peak of the frequency characteristic curve represents the resonant frequency of the part. This is the frequency on which the part vibrates with the highest amplitude:



In this case, the amplitude frequency transmission characteristic is often simply called the **amplitude frequency spectrum** or only the **frequency spectrum** of the vibration signal.

Because the input excitation function is equal to one, the spectrum can be obtained directly by applying FFT to the oscillation signal of the tested part measured mostly by an accelerometer (see Task 4).

Equipment needed for the experiment

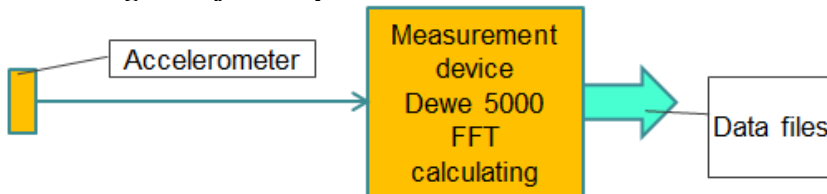
- Hammer for excitation of Dirac's impulse
- System for measuring and recording the required values - acceleration and possibilities of calculating FFT
 - o Vibration sensor of tested part (mostly an accelerometer because of easy use)
- System for processing the results - data files
 - o PC and SW (matlab or spreadsheet editor, e.g. Excel, Calc)

3. The actual experiment procedure

Equipment used:

- DEWE5000 measuring device
- Techlab 50G accelerometer
- Hammer

Block diagram of the experiment:



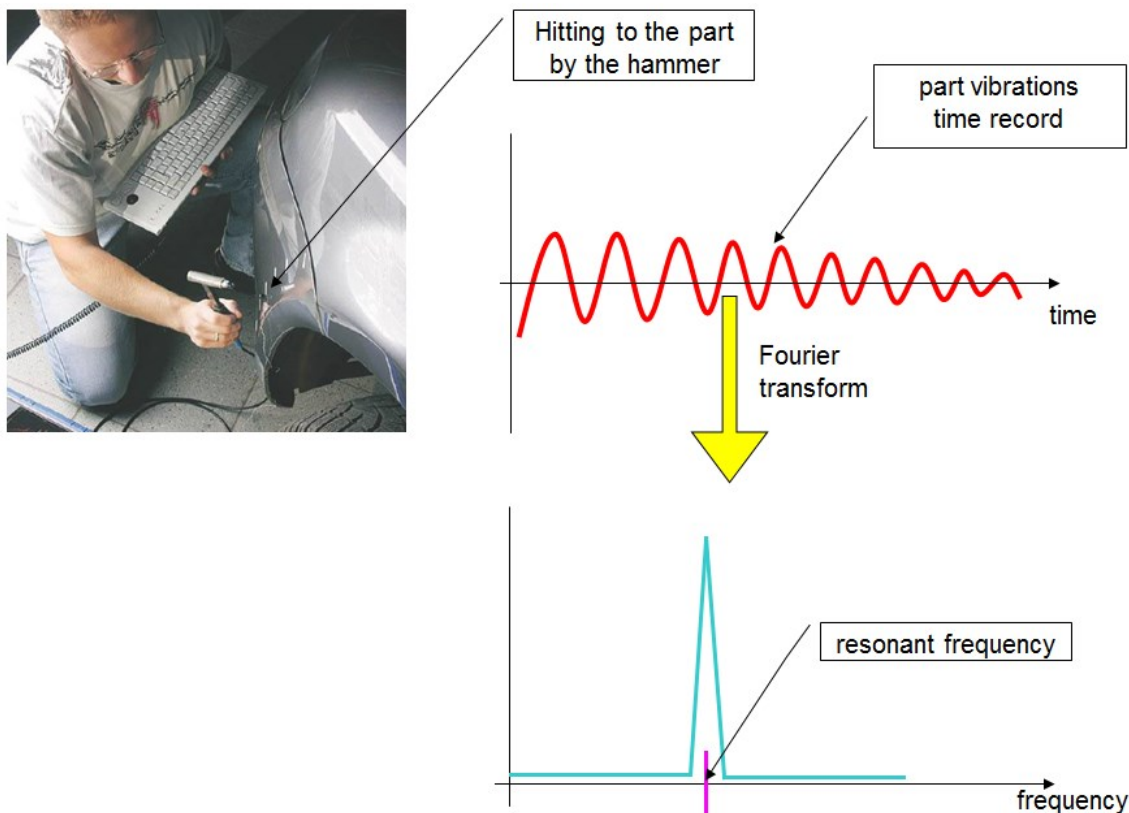
Preparation of the experiment

The Dewe 5000 system is used to data record and FFT calculating. The experiment requires:

- To set the measuring and recording parameters of the signal from the accelerometer
- Definition of mathematical channels for calculating FFT from the measured signal
- Create a trigger condition to start and stop recording so that data files are not unnecessarily large at a high sampling rate

Experiment procedure:

- Installing the accelerometer on the tested part
- Starting recording, hammer stroke
- Analysis of the measured amplitude transmission characteristic

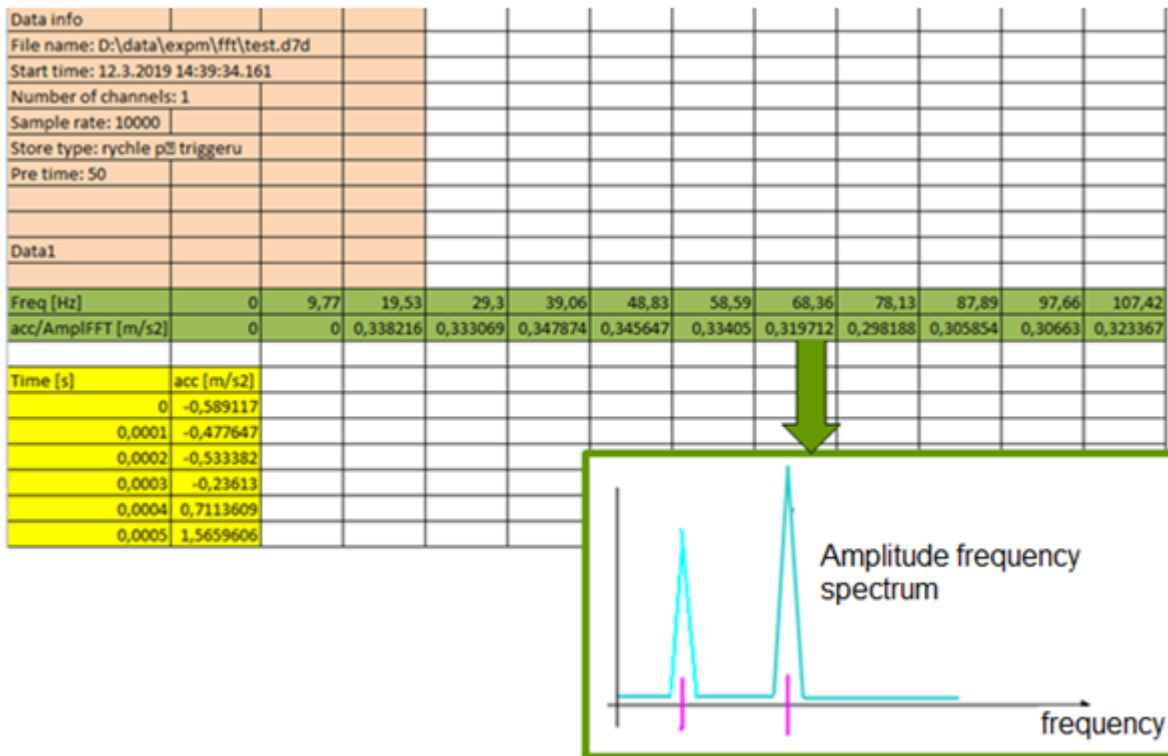


4. Processing the measured data and presenting the results

The exported data have the same format as in Task 4. The time progress of the oscillation, as well as the calculated FFT is stored in one file.

At the beginning of the file there is a header (highlighted in pink), then two rows (highlighted in green) with the FFT record (here unlike task 4, PSD is not calculated, therefore only 2 lines) and then two columns with the time progress of the oscillation (highlighted in yellow).

The main output of the experiment, i.e. the amplitude frequency spectrum of vibrations is obtained by plotting the graph X-Y from the two rows of the FFT record (here in green). On the axis X there will be the first row - frequency, on the Y axis there will be the second row, i.e. amplitude.



The frequency value(s) with the maximum amplitude can be read from the displayed spectrum. This (those) is the resonance frequency (frequencies) of the tested part. The read values can be displayed in the Table.

Task 7: The measurement device setting, measurement of the calibration curve

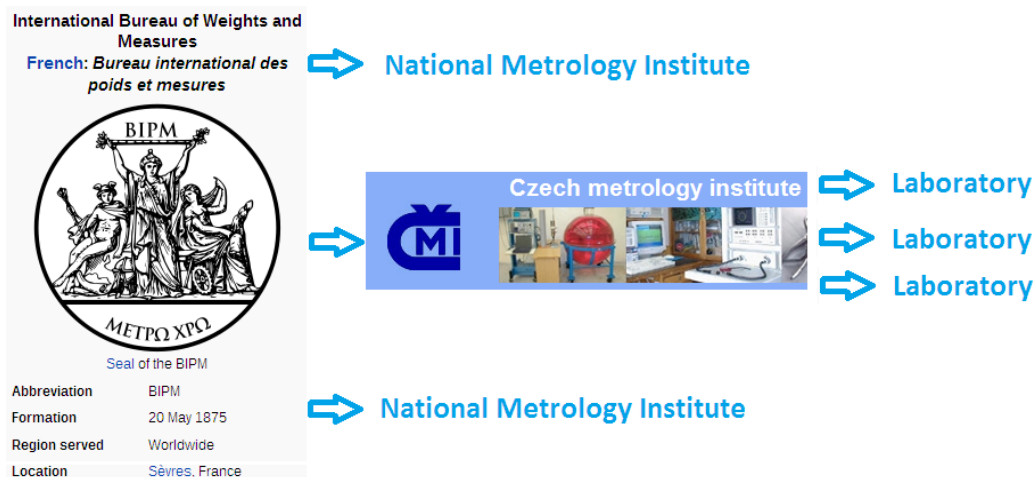
1. Task

- Connect the LWG resistance position sensor (supply 10V, range as necessary) to the measuring device. Set the measuring channel (name, unit). Set the sensitivity of the sensor, use the values of two known position points.
- Compare the value of the connected sensor with the etalon through the whole range of the sensor.
- Display the position measuring calibration curve.
- Determine the maximum relative error of the position measuring.

2. Theoretical analysis of the experiment

Etalon gauge

An etalon is a gauge with precision verified by a superior institution. It is not used directly for measuring but it verifies the accuracy of other meters at a lower level. The etalon must always have higher class of precision than the gauge which is being verified.



Calibration curve

The calibration curve determines the relative error progress of measuring through the whole range of the used sensor. To determine there must be a comparison gauge - etalon. Both sensors are mechanically linked and, in several steps, the measured physical quantity is changed over the whole range. In each step the value of the sensor and the etalon is recorded. From this data the deviation of the measured and actual value Δy is calculated for each step:

$$\Delta y = y_{\text{sensor}} - y_{\text{etalon}}$$

and the relative error δ as the measured deviation relative to the range of the sensor (often expressed as a percentage):

$$\delta = \frac{\Delta y}{\text{sensor range}} \quad \delta = \frac{\Delta y}{\text{sensor range}} * 100 [\%]$$

The calibration curve is the dependence of the actual error on the input measured value. It determines how the measuring relative error changes through the whole range of the sensor. The

calibration curve (and the maximum measurement error) applies only until there is a change in the measuring chain connection. For the complete non-detachable gauges (digital calliper, weight, etc.) it is simple, no change in the chain can occur. For the universal measuring systems (i.e. universal multi-channel device and various sensors), the calibration applies only for one particular connection. Moreover, the calibration can be restricted by time, internal regulations may require its periodical repetition.

Equipment needed for the experiment

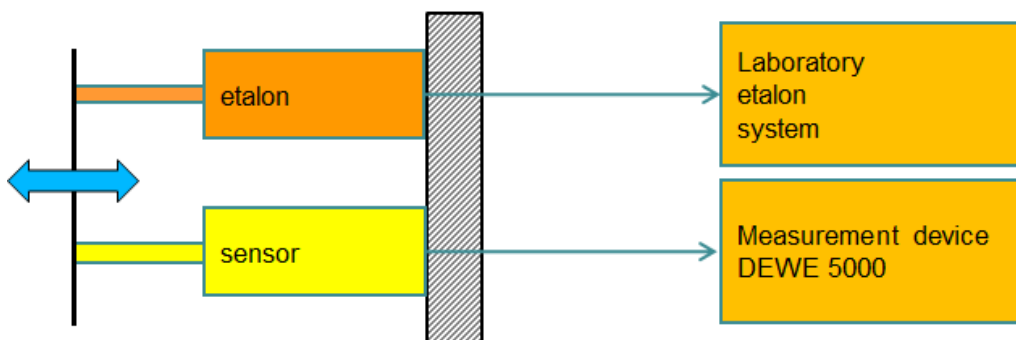
- Some measurement device
- Position sensor
- Etalon position sensor
- System for processing the results (PC and SW Matlab, Excel,...)

3. The actual experiment procedure

Used equipment

- DEWE 5000 measurement device
- LWG position sensor, various ranges
- Laboratory etalon system with a Renishaw position sensor

Block diagram of the experiment



Preparation of the experiment

- Inserting the tested sensor into the etalon system's anchor unit
- Setting the positions of the unit according to the range of the sensor

Experiment procedure

- ***Connect the sensor to DEWE5000, set the sensitivity from two known points:***
 - Select the channel on DEWE500, set the name and units
 - Set the supply voltage
 - Connect the sensor
 - Set the range of the channel, check according to the range of the sensor
 - Set the sensitivity from two points:
 - set the first point at the beginning of the range x_1 and measure the output value y_1
 - set the second point at the end of the range x_2 and measure the output value y_2
 - the software will calculate the sensitivity from this data according to the formula:

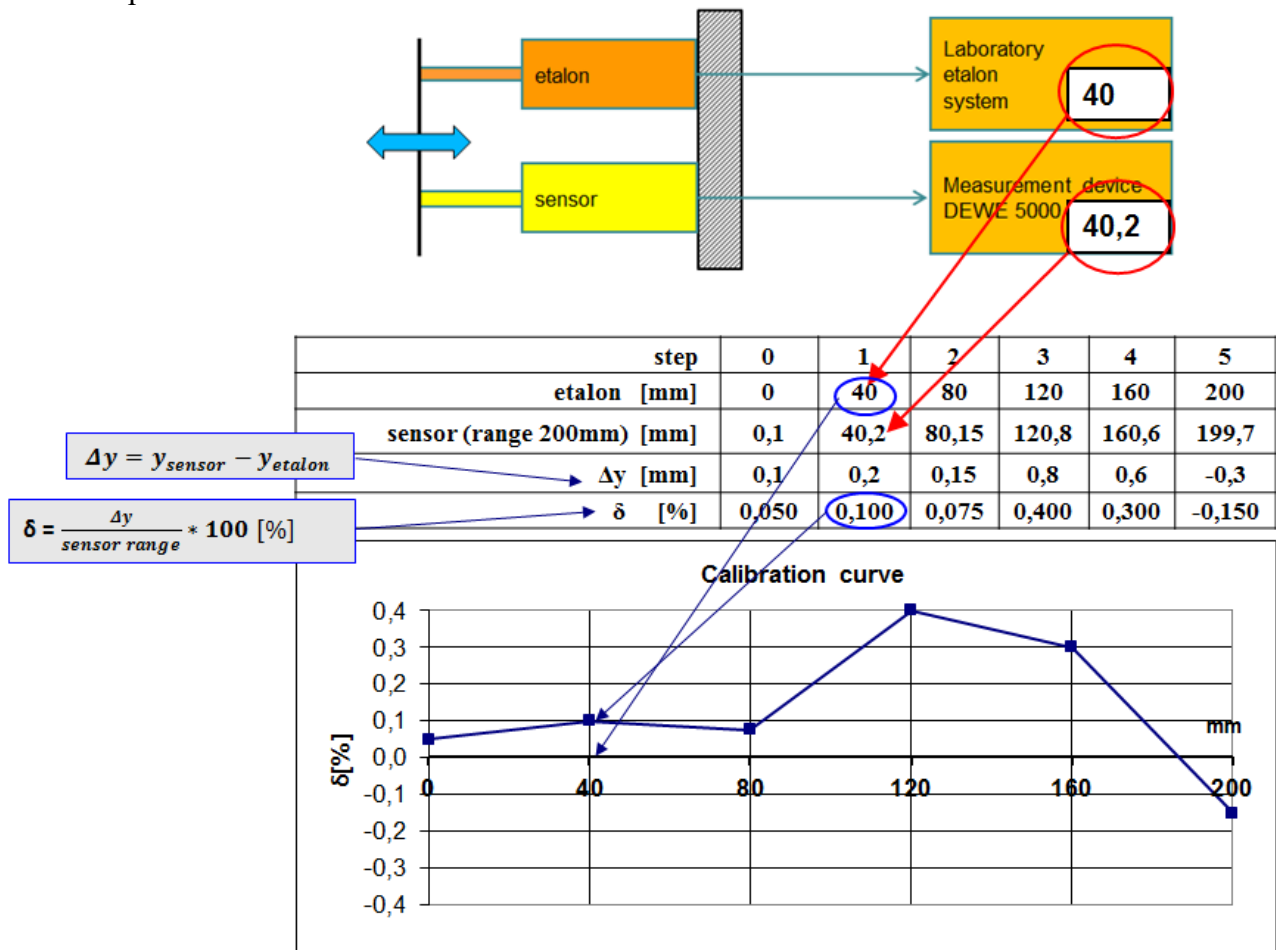
$$k = \frac{y_2 - y_1}{x_2 - x_1}$$

▪ **Measuring calibration curve of the channel for measuring position**

- Set the 1st point at the beginning of the range and measure the value of the position and the etalon channel.
- Set another point and measure the value of the position and the etalon channel.
- Measure several points in this way (about 5 to 6 through the whole range).

4. Processing the measured data and presenting the results

The value of deviation Δy and the relative error δ is calculated from the measured values of the sensor and the etalon for each point (in the example below, a sensor range of 200 mm is used). The relative error values expressed graphically depending on the position, are called the calibration curve. The calibration curve is not a continuous line but consists of linear lines between individual measured points.



In conclusion, the maximum relative errors can be determined. Essentially, this indicates that across the entire range of position measurement, the measurement error is less (maximum equal to) this value.

Task 8: Measurement of a part mechanical stress during operation

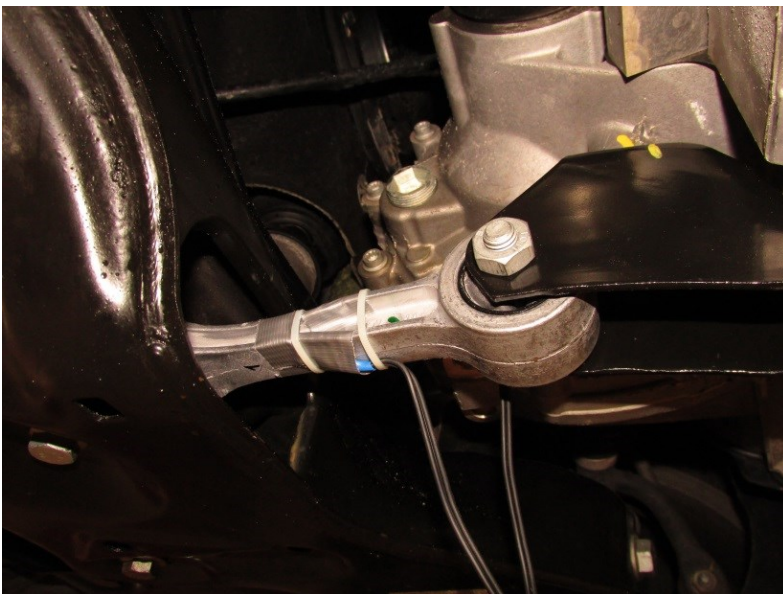
1. Task

- Measure the normal stress of the car engine torque strut during operation.
- Display graphically the measured course of normal stress.
- Determine if the mechanical stress does not exceed the permissible limit for the torque strut material made of aluminium alloy.

2. Theoretical analysis of the experiment

Introductory note:

Measuring stress during operation would mean actual driving, which is not feasible in school teaching. Therefore, the driving stress will be simulated in the laboratory using a hydraulic engine, the load will be realized by the actually measured data. But everything else will be the same as the real measurement. The task thus shows a procedure how to measure the actual stress of a part that is part of a larger unit without the need for its disassembly and any other modifications. It does not have to be just an automotive part, the same can be done for any part (for example, a bridge girder), for which it is necessary to verify its real load during operation. The picture shows the torque strut and its installation in the car:



Measurement options:

Mechanical stress is a condition that arises in the body by external forces. The stress actually indicates the internal distribution of forces per unit area. See task no.2 for more.

The normal stress σ [Pa] is defined by the relation:

$$\sigma = \frac{F}{S} \quad \text{where } F \text{ is the force acting in the direction of the axis [N]} \\ S \text{ is the sample area perpendicular to the axis [m}^2\text{]}$$

Therefore, if the tested part has to remain mounted in the device as standard, direct determination of the normal stress is impossible, because we cannot measure the force by which the part is loaded.

However, to measure the normal stress, it is possible to use the deformation of the part due to its loading. The relative elongation ϵ is used to define the deformation of the part:

$$\epsilon = \frac{\Delta l}{l} \quad \begin{array}{l} \text{where } \Delta l \text{ is elongation [m]} \\ l \text{ is initial length [m]} \end{array}$$

Relative elongation is a dimensionless quantity, but is very often reported as [$\mu\text{m} / \text{m}$], which better expresses its very small value.

A clear relationship between the normal stress σ and the relative elongation ϵ in the area of elastic deformation is defined - Young's modulus of elasticity E [Pa]:

$$\sigma = E * \epsilon$$

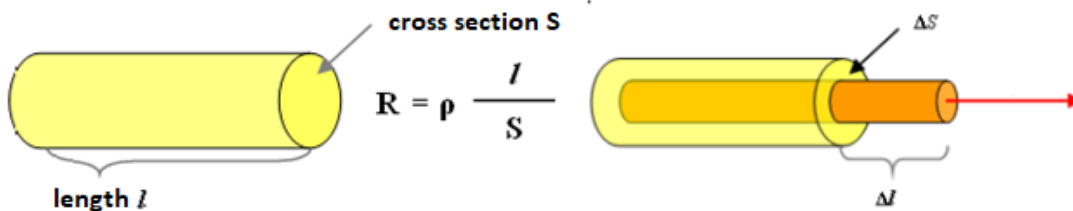
To convert ϵ to σ , it is therefore necessary to know the properties of the material from which the part is made. This can be problematic, for example, for a part from another manufacturer, where we do not know the exact composition of its material. Then all that remains is to use tabulated values for the given material type. This will also be the case in this case, the tabulated values for the aluminum alloy will be used for the conversion:

- Young's modulus of elasticity $E = 71 \text{ Gpa}$
- yield strength $R_E = 280 \text{ Mpa}$
- breaking strength $R_M = 310 \text{ MPa}$

The value of the normal stress will therefore be obtained by conversion from a relative elongation, which can already be well measured on a part that cannot be dismantled. Only a small space for the installation of a deformation sensor (strain gauge) on the part is needed.

Strain gauge:

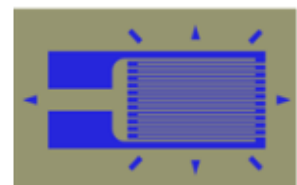
As early as 1843, Mr. Wheatstone discovered that the electrical resistance R [Ω] of a conductor depends on its dimensions:



If the dimensions of the conductor are deformed due to mechanical loads, its resistance will also change. The strain gauge is based on this principle. An electric wire is glued to the surface of the object. Deformation of the object will also deform the glued conductor and thus change its electrical resistance. The change in the resistance of the conductor is proportional to the deformation and in the area of elastic deformation the following applies:

$$\frac{\Delta R}{R} = K * \frac{\Delta l}{l} = K * \epsilon \quad \text{where } K \text{ is the strain gauge constant (according to the conductor material)}$$

Commercially produced strain gauges are used for practical use. Most often in a foil design, where an electrically conductive layer in the shape of a meander is applied to the insulating foil. This design increases the length of the conductor and the change in resistance with deformation is therefore also greater. The value of the constant $K \approx 2$ is typical for this type of strain gauges. The meander is made so that the strain gauge measures the elongation only in its longitudinal direction and is minimally sensitive to deformations in the transverse direction.



The strain gauge is glued to the test object so that it deforms together with it. The meander of the strain gauge must be in the direction of the evaluated deformation. By evaluating the change in its resistance, the relative elongation ϵ is measured.

Equipment needed for the experiment

- Foil strain gauge
- System for measuring and recording the progress of the relative elongation and its recalculating to σ
- System for processing of the results - data files
 - o PC and SW (matlab or spreadsheet editor, e.g. Excel, Calc)
- The hydraulic engine to simulate the load during driving for this simulated experiment
 - o Its control system and real load data record

3. The actual experiment procedure

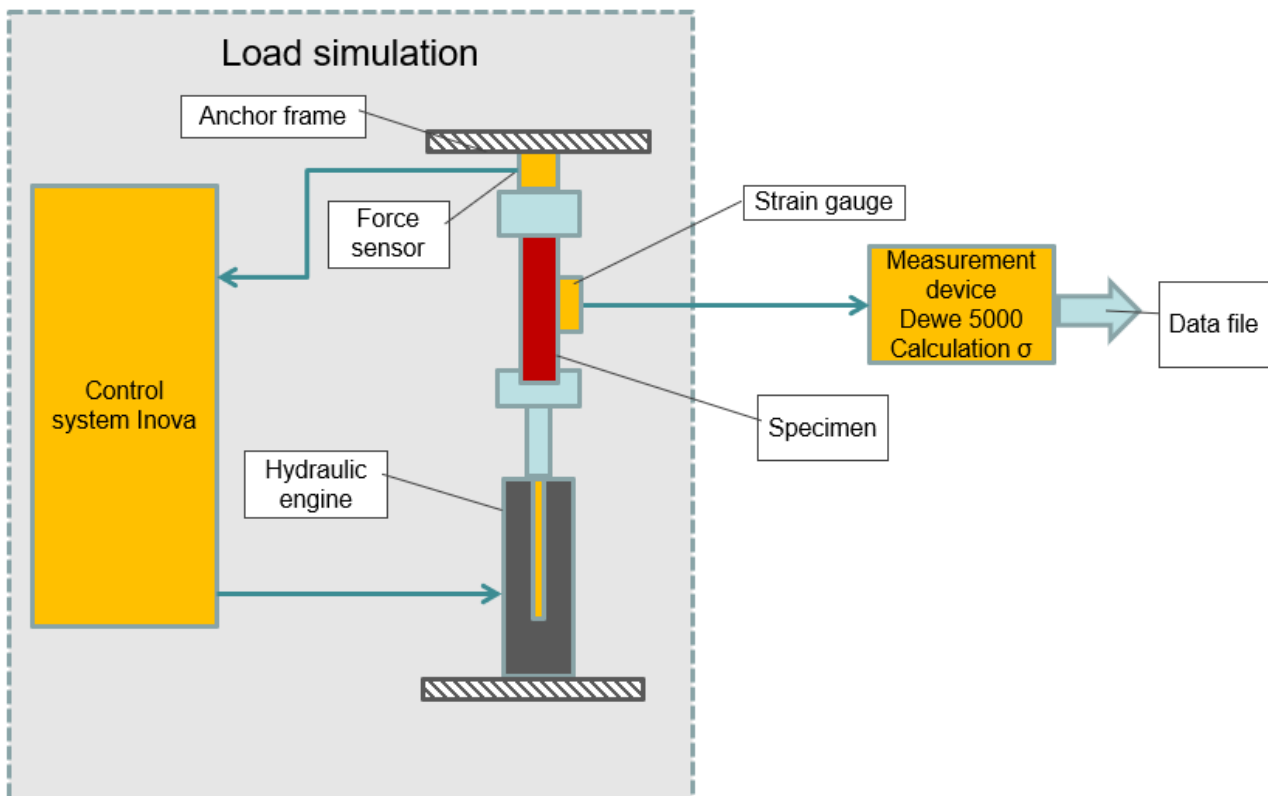
Used equipment

- HBM 1-LY11-6/350 single axis foil strain gauge
- DEWE 5000 measuring device

for load simulation added here

- Hydraulic engine Inova AH 25-250
- Anchor frame
- Inova EU 3000 control system for hydraulic engine control, data file with real load record

Block diagram of the experiment



Preparation of the experiment

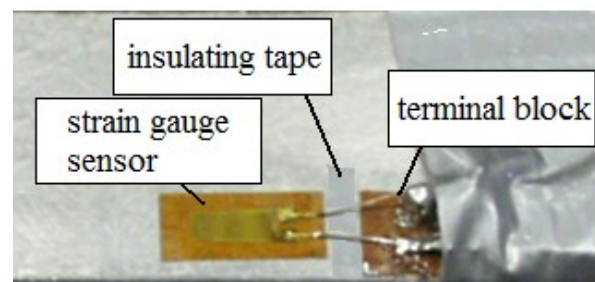
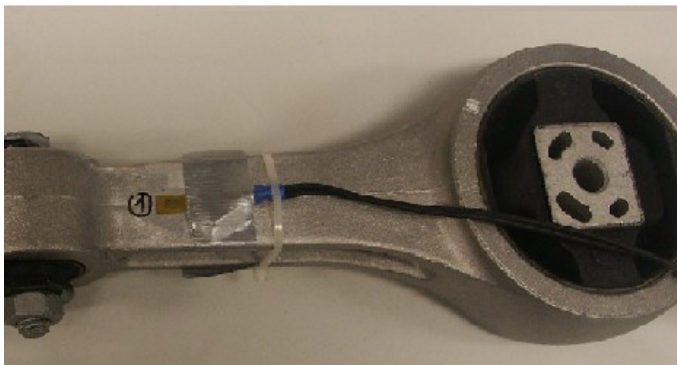
▪ Strain gauge gluing

In a real experiment, the first step would be to glue the strain gauge to the test part. The strain gauge is glued in the longitudinal direction of the meander in the direction of the measured deformation. There are a variety of adhesives from one - component cyanoacrylate adhesive to two-component epoxies. These can be cured at normal or elevated temperatures. The quality of the adhesive mainly affects the long-term stability of the bonding and temperature resistance. For short-term measurements, it is enough to use a one - component adhesive for gluing strain gauges. The adhesive must transfer the deformation of the part to the strain gauge, so it must have precisely defined properties.

In this task, the strain gauge is already glued, so only the gluing procedure is given here:t

- the part surface treatment
 - smoothing with sandpaper
 - cleaning, degreasing
- gluing insulating tape to prevent contact of the connecting wires with the pad
- gluing of the strain gauge
 - thin layer of glue
 - manipulation with tweezers to avoid greasing the surface with your fingers
 - soldering of strain gauge terminals to the terminal board
 - resistance value check
 - soldering of the cable to the terminal board

The installation of the strain gauge can be seen in the following figure:

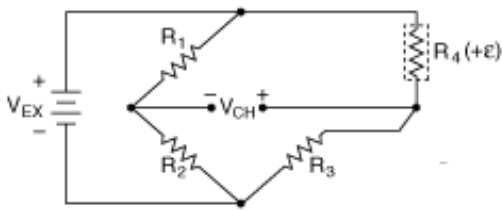


▪ Strain gauge connection

The change in the resistance of the strain gauge with deformation is very small and therefore the bridge connection is used almost exclusively for its evaluation. This is done by four strain gauges that are connected to a differential amplifier. The use of 4 strain gauges is financially and spatially demanding, so very often two or even three strain gauges in a bridge are replaced by fixed resistors. In the simplest case, only one strain gauge and three resistors are used, this connection is referred to as a quarter bridge (1/4 of the bridge is a strain gauge). However, the quarter bridge is very thermally unstable, because the strain gauge is also sensitive to temperature in addition to deformation, and in this connection the temperature effect cannot be compensated in any way. This connection can therefore only be used for cases where there are no temperature fluctuations during the experiment.

In this way, the strain gauge is also connected to the torque strut.

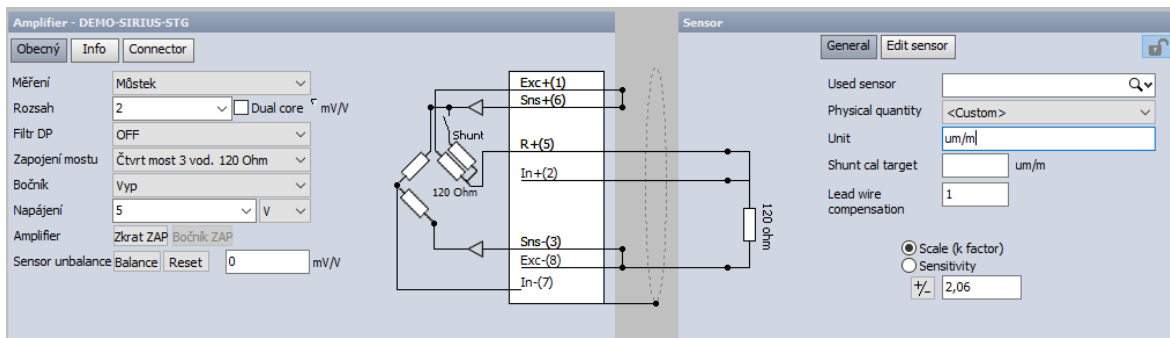
The connection principle is shown in the following figure:



The number of strain gauges used and their orientation to deformation (when using more strain gauges) affects the conversion of the change in their resistances to ϵ . There are a total of 7 possible combinations of gluing and connecting for which conversion relationships are defined. In this case, it is a quarter bridge with one strain gauge loaded by tension or pressure:

MEASURES	TYPE	BRIDGE	EQUATION V_{out}/V_{in}	BRIDGE FACTOR	LINEAR	DESCRIPTION
 tension, compression	quarter	 V_{out} V_{in}	$\frac{k \cdot \epsilon}{4 + 2 \cdot k \cdot \epsilon}$	1	no	Single gage measuring tension and compression - basic configuration

Modern measurement devices have built-in everything needed to connect a strain gauge, ie a power supply, differential amplifier and resistors for bridge completion. Only the specific connection type, strain gauge constant and conversion relationship are selected using the SW settings. The corresponding connection diagram to the measurement device connector is already directly listed in the settings panel. The output of the measured channel is then directly the value ϵ .



▪ Calculation of σ

Using the mathematical channel, the conversion of ϵ to σ is performed using the value of Young's modulus of elasticity E.

Experiment procedure

- anchoring of the strut to the loading machine (simulation of assembly in the car)
- connection of the strain gauge to the measurement device, setting of the measuring channel
- bridge balancing - resetting the initial value
- start recording and load simulation

4. Processing the measured data and presenting the results

Data processing will be very simple in this case, because there will already be a time record of the value of σ in the data file. All you have to do is display it graphically.

For complete processing, it is then necessary to compare whether the load peaks do not exceed the allowable value of the load, which is usually the yield strength of the material (from a safety point of view, a lower value can be determined). In this case, the above value of yield strength

$R_E = 280 \text{ MPa}$ is used as a criterion.

Task 9: Measurement of the scooter's beam deflection during riding

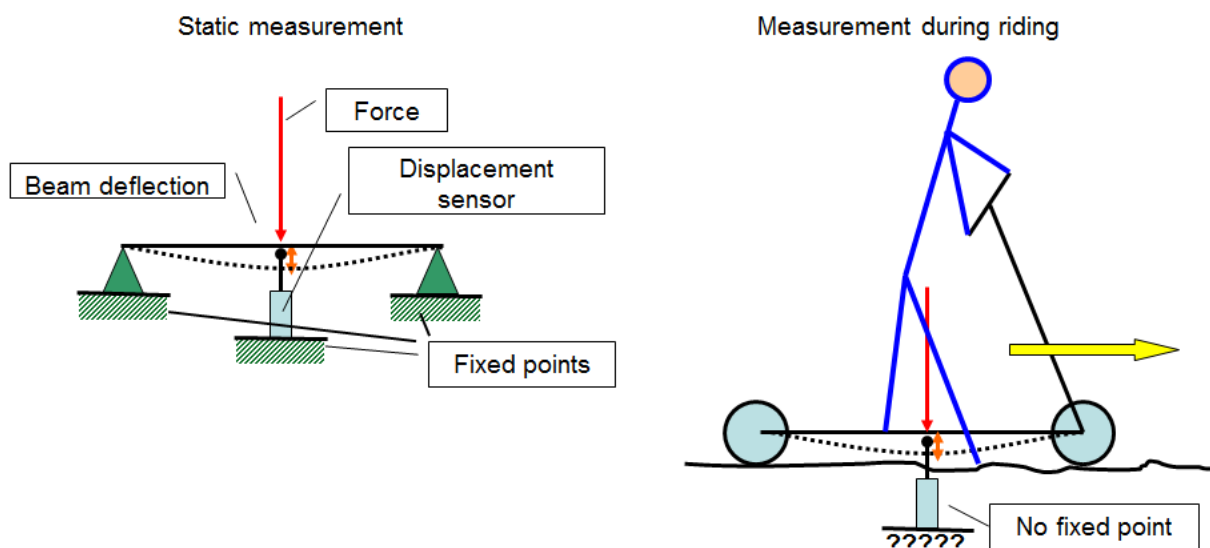
1. Task

- Measure the value of the deflection of a scooter's beam when riding on a plain surface and overcoming an obstacle (e.g. a step). For better orientation in the measured data, use the video record of the action in progress.
- Display the time progress of the deflection.
- Create a video record of the synchronous data recording and the image.

2. Theoretical analysis of the experiment

Problems of measuring deflection during riding

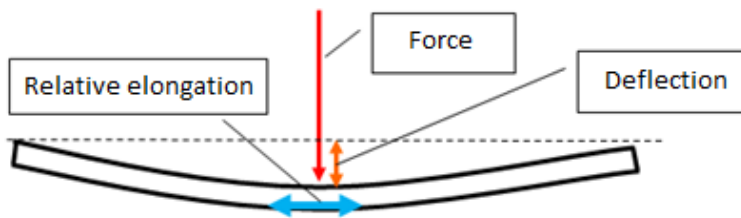
Measuring the beam deflection in a static case is simple because there are fixed points for mounting the beam and sensor. On the other hand, direct measurement of the beam deflection during riding is virtually impossible, because no fixed points can be used.



Measurement beam deflection by the contact-free sensor of the distance between the beam and the floor is also impossible - the deflection of the beam is very small, and the measured value would be affected by the unevenness of the floor. The change of this distance is also significantly affected by tyre deformation which can be much greater than the deflection of the beam.

An indirect method must be used to measure the deflection. Another physical value will be measured which is proportional to the deflection and where a fix point is not needed. Before measuring during riding a static measurement is carried out to obtain the conversion relationship between the deflection and the measured quantity. Using this relationship, the obtained measurement data when riding is then converted to the deflection value.

A suitable value may be the relative elongation of the beam. It can be assumed that the relative elongation of the beam surface is proportional to its deflection and to measure the relative elongation no fix point is needed:



Principle of relative elongation measuring with a strain gauge

The principle of measuring the relative elongation was described in the task 8.

Video recording of the action

Any camera can be used for video recording the action. In this case, the video is not synchronized with the measured data. Advanced measuring systems allow the camera output to be connected as one of the measured signals and then the video is fully synchronized with measured data.

Equipment needed for the experiment

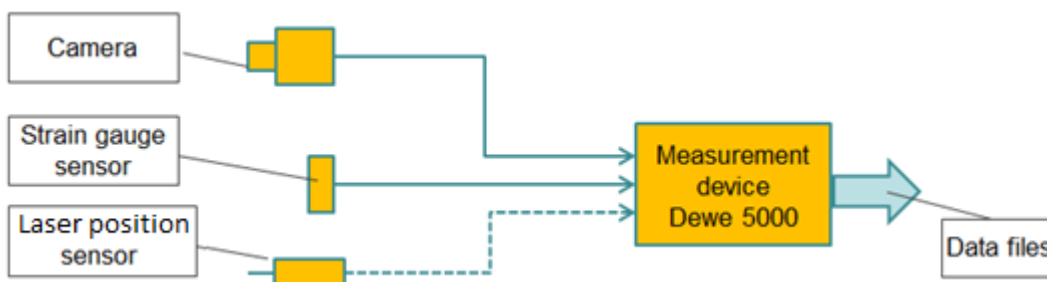
- Foil strain gauge
- System for measuring and recording the progress of the required values – relative elongation and video signal from camera
 - o Camera for video record
 - o Position sensor for calibrating the strain gauge signal
- System for processing and analysis of the results - data and image files
 - o Free version of the software Dewesoft

3. The actual experiment procedure

Used equipment

- HBM 1-LY11-6/350 single axis foil strain gauge
- DEWE 5000 measuring device
- DS-CAM high speed camera
- Laser position sensor for obtaining the conversion equation between the beam deflection and its relative elongation

Block diagram of the experiment



Preparation of the experiment

▪ **Strain gauge installation**

The strain gauge is already glued, the gluing procedure is described in the task 8.

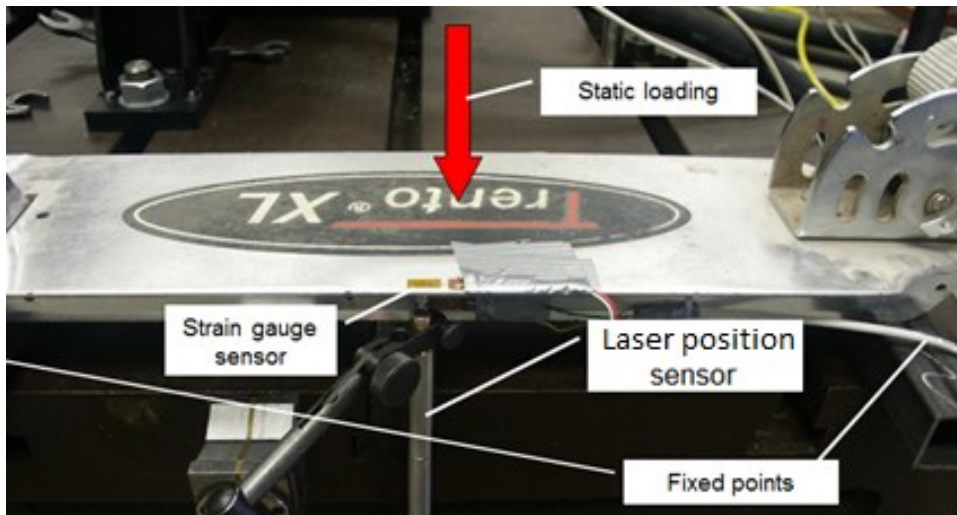
- **Strain gauge connection**

One active strain gauge is used for the measurement, which is connected as a quarter bridge, ie connection without temperature compensation (details in the task 8). Measurements at constant temperatures are assumed. In this case, the standard conversion formula will not be used for the measurement, because we do not want to measure directly ϵ , but the deflection of the beam. The conversion relationship is obtained by calibration in static mode.

- **Calibrating the strain gauge signal on the beam deflection**

During static loading, obtain the conversion equation between the elongation of the beam and its deflection

- mount the beam in two places on supports
- install the laser position sensor for the measuring the beam deflection



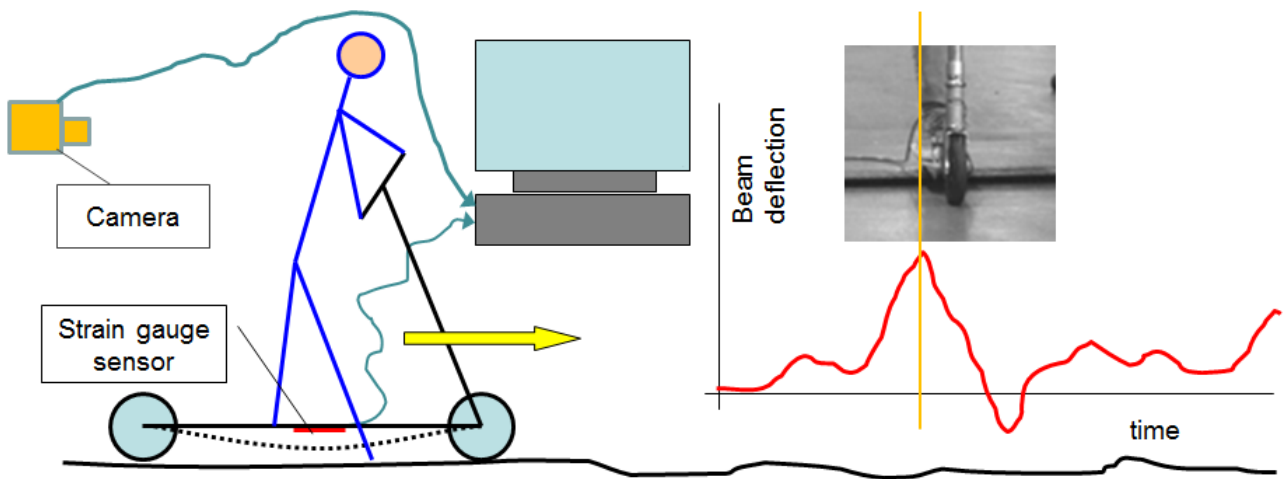
- set the conversion constant of the strain gauge signal on the elongation by two points (zero loading / maximum loading), save the settings
- check the linearity by comparing multiple points

Experiment procedure

- **The measurement device and camera preparation**

- disconnecting the position sensor from the measurement device
- connecting and setting the camera
 - video frequency setting, aperture and camera focus
 - checking the lighting

- synchronous recording of the signal from the strain gauge (elongation of the beam) and the video during the scooter riding



4. Processing the measured data and presenting the results

The Dewe 5000 measuring system creates binary data files when measuring. After the measuring, they must be exported into generally readable files. The resulting files are in standard form, no special formatting of the input is needed. So the beam deflection data can be exported in a generally readable format for further processing. However, the synchronisation with the video will be lost by this procedure.

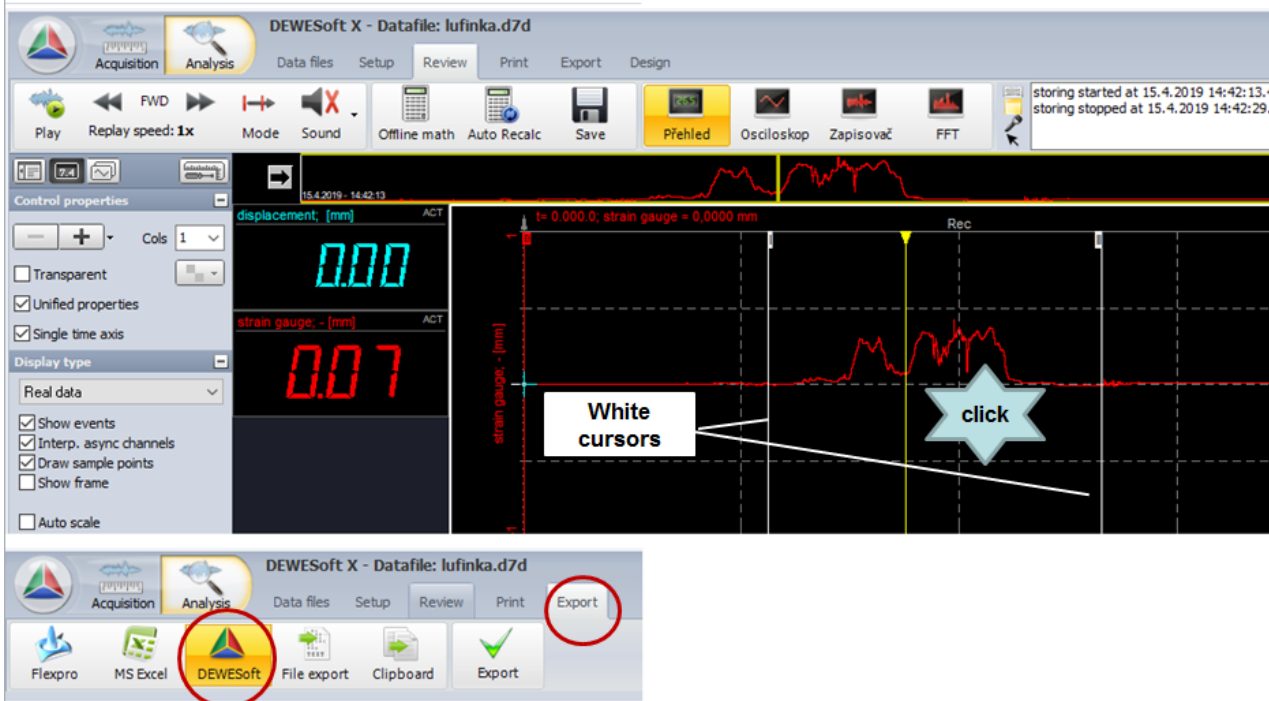
If it is necessary to keep the option of analysing the data, including synchronous image, identical software must be used for the analysis, in this case Dewesoft. This software for the analysis can be obtained free of charge at www.dewesoft.com – *support* – *downloads*. The version must be identical or higher than the version on the measuring exchange, i.e. version 7 or higher.

If the record contains data and image they are stored in two independent files. The data file has the format *name.d7d* and the associated video file *name.cam0.dvi*. Both files must be located in the same directory. To process the data, the data file is always opened in Dewesoft, the video file is opened automatically.

Basic Dewesoft software modifications:

▪ **Cropping the data file**

The data and video record may contain an "empty space", i.e., part of the record has no information value. This is usually at the beginning or end, because the recording started early or ended late. White cursors can be used to delimit the section with the required record which can be enlarged into the graph by clicking between these cursors. The selected section can be exported into a new file. On the export tab, choose the Dewesoft file type, the save folder and the new name. After clicking on the export button, only the selected section is stored, the data and video are automatically cropped.



This new file can be used for further processing.

▪ **Exporting data**

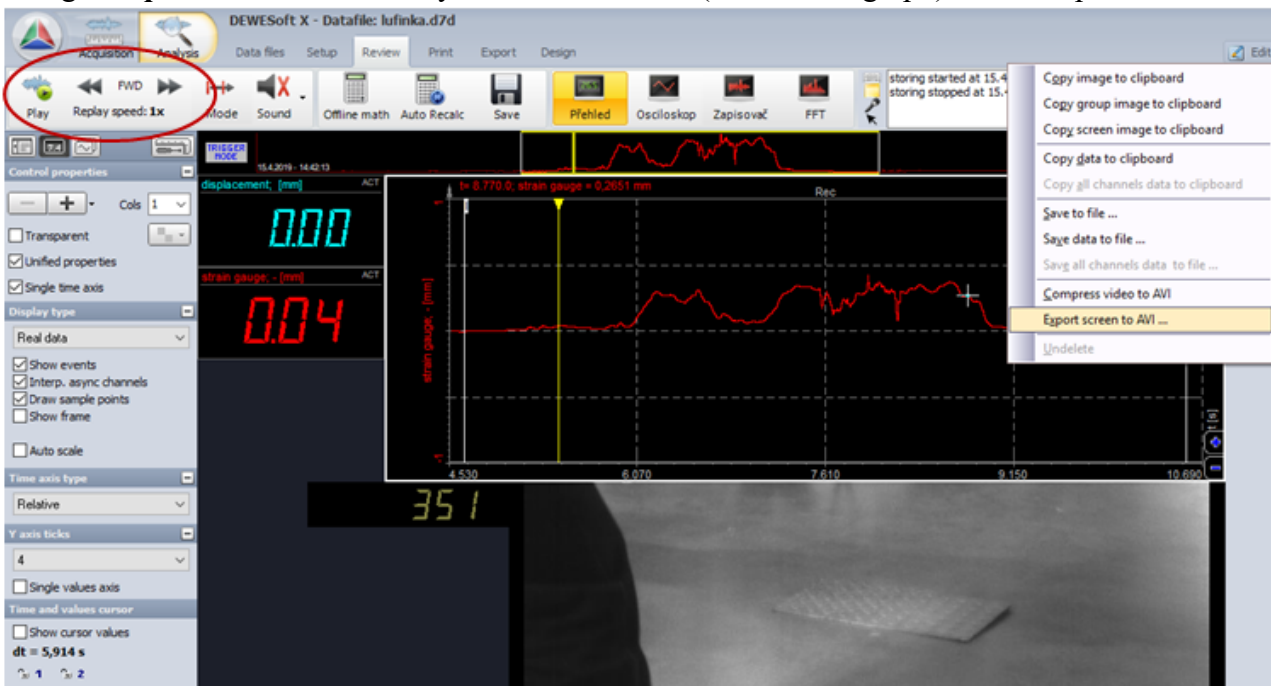
Recorded data can be exported in a generally readable format. Again on the **Export tab** select **File export** and choose the format of the data – mostly *.txt or *.csv. The section displayed in the graph is exported to the text file, however now only the data without the video file.

▪ **Exporting the action record into the video standard file**

Dewesoft allows you to replay the recorded action at the selected speed. In the left upper corner on the Review tab, the replay speed can be set and it can be run by clicking on Play. The yellow cursor moves across the graph and the video record is replayed synchronously. Play always runs from the actual position of the yellow cursor, for a new replay the cursor must be manually moved back to the beginning.

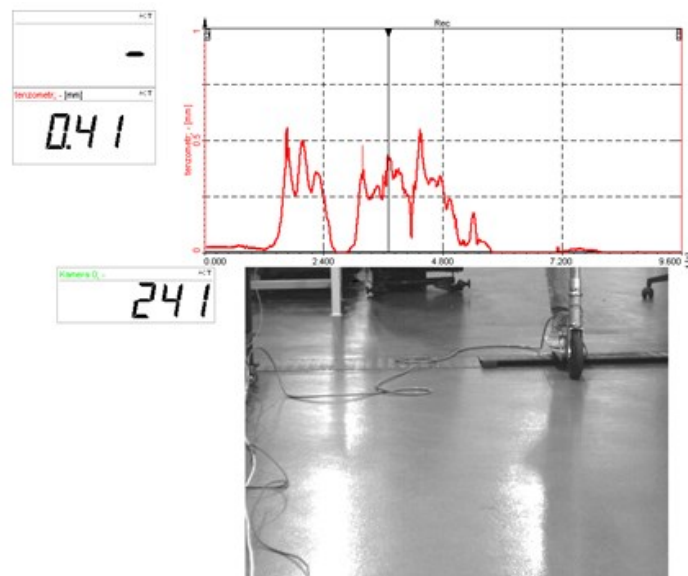
“**Edit menu**” is in the upper right corner of the Dewesoft window. Here select “**Export screen to avi**” and then select the directory and the file name. The entire screen (graph and video) will be exported to a file according to the “**Replay**” settings.

Using **Compress video to AVI** only the video window (without the graph) can be exported.



▪ **Copy screen image to clipboard**

Using “**Copy screen image to clipboard**” in the “**Edit menu**” the static image of the actual screen can be exported to clipboard



Task 10: Crash test

1. Task

- Measure the position change of the tested part after an impact at 50 km/h. Record the action during the impact with a camera.
- Display the time recording of the measured data.
- Create a video record of the synchronous data and video record.

2. Theoretical analysis of the experiment

Problems of carrying out the crash test

The crash test simulates the collision of a car or various parts of a car (bumpers, head rests, etc.) with an obstacle. In the case of the whole car, the car hits the defined obstacle at the specified speed. With individual parts, the test is carried out in the opposite way, i.e. the tested part is firmly fixed and hit by moving mass - impactor. Another way is to fix the tested part on the impactor and run the whole unit into a obstacle. What is important is that at the moment of impact, the impactor moves only with the inertia, its movement is not controlled in any case. First of all, the impactor is accelerated by the engine (possibly by gravitation) to the required speed, the engine then brakes and the impactor continues to move by inertia up to the impact. This test best corresponds the to a real-life process.

During the crash test, the speed and energy of the impact is always stated. The speed of the impact is derived from the acceleration of the engine, the impact energy is then determined by the weight and the speed of the impactor:

$$E = \frac{1}{2} m * v^2$$

In an impact, the speed of the impact must be exactly kept and recorded. Furthermore, the image of the current process and data from various sensors describing the behaviour of the test item are usually recorded.

A very important part of the crash test is to ensure a defined path for impactor movement. At the moment of impact, it must move by inertia and must not be anchored to the engine. Therefore, to ensure the defined route, various lines are used, for example rails. An example of the arrangement is shown in the following figure:

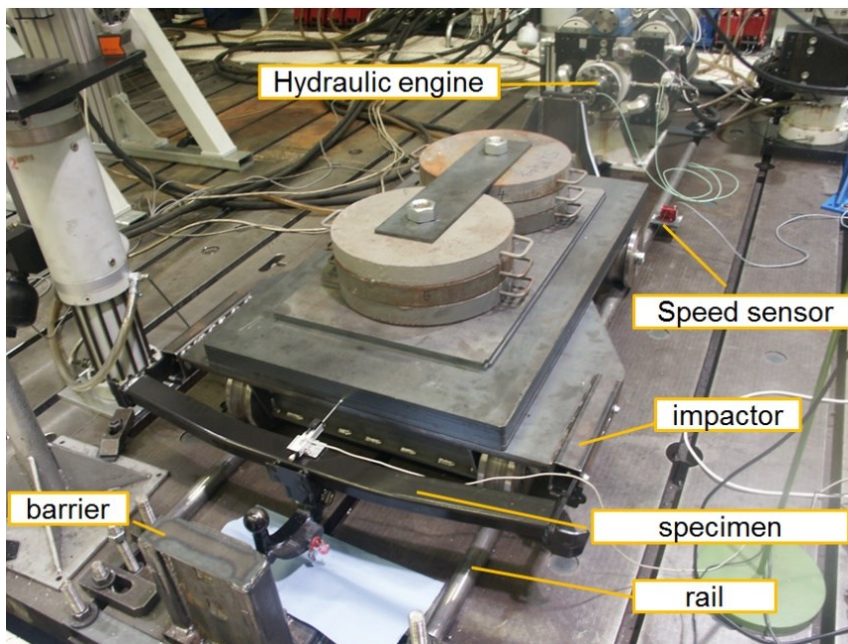


Image recording of the action

For the image recording of the action in crash tests a special camera is used that allows fast recording (thousands to tens of thousands images per second). In this case, because of the large amount of data, first of all the file is directly stored in the camera memory and then, after finishing the recording, it is transferred to permanent storage. The length of the recording is restricted by the memory capacity of the camera mostly to several seconds. Therefore, the recording must start based on a condition - mostly the impactor reaching the set position.

If the image recording speed requirements are not high, a camera connected directly to the measuring equipment can be used. The image data is stored together with data from measuring sensors directly on the measuring equipment disc. The recording time is limited only by the capacity of the disc, however the achieved image recording speeds are several hundreds of images per second. The greatest advantage of this solution is automatic full synchronization of the image records with the data. The action can be analysed in real time in one device without an additional manual merge of data and image.

In both cases good lighting of the recording space must be considered. The required light intensity is proportional to the recording speed. For very fast records, the quality of the lighting is decisive for the resulting record. Fluorescent or discharge lamps cannot be used for illumination, as they basically “flash” with the mains frequency. This cannot be seen by the naked eye, but it is seen on a recording by fast camera. Sources with a constant lighting flow e.g. a standard bulb must be used for lighting. Here, in case of powerful light sources, attention must be paid to the fact that the high thermal radiation may heat the surface of the specimen. Currently, LED based diodes supplied by DC sources seem to be the ideal lighting sources. At present, LED diodes are sufficiently powerful and do not load the sample with thermal radiation. Their DC supply ensures a constant lighting flow.

Equipment needed for the experiment

- Equipment for accelerating the impactor to the required speed.
- The impactor mounted on a line to keep the specified route
- System for measuring and recording the progress of the required values - speed, displacement and image information
 - o Impactor displacement and speed sensor.
 - o Tested part state sensor

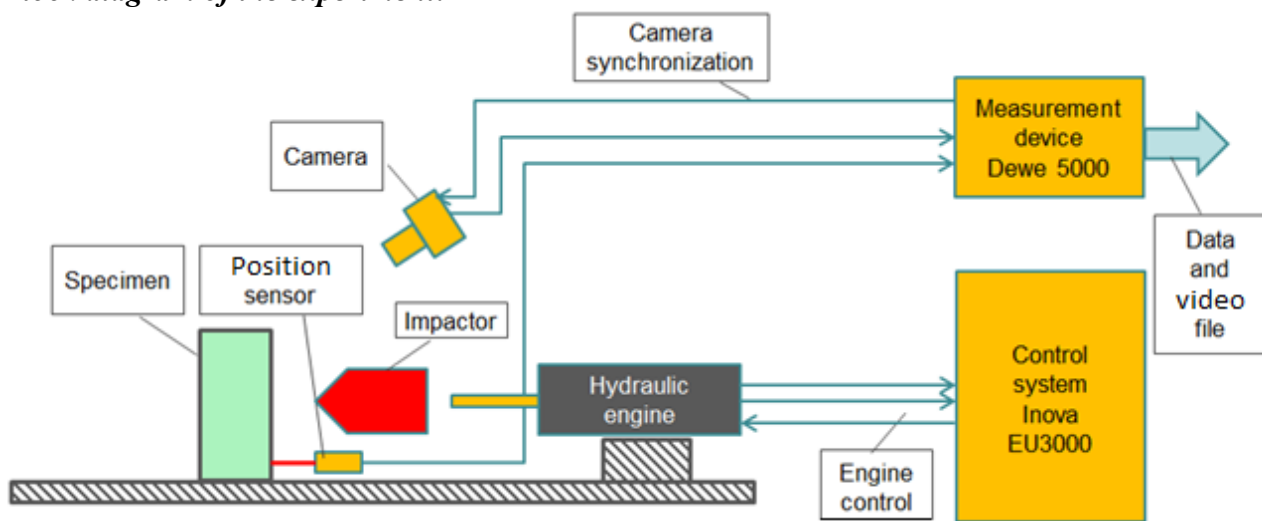
- Video camera
- Lighting source
- System for processing and analysis of the results - data and image files

3. The actual experiment procedure

Equipment used:

- Inova AH 35-400 hydraulic motor (max.: 35kN, 400 mm, 15 m/s)
- Impactor with guidance
- Inova EU 3000 control system to the hydraulic engine control
- DEWE 5000 measurement device
- DS-CAM camera
- Position and impactor speed sensor
- Laser position sensor of the tested part
- LED lighting sources

Block diagram of the experiment:



Preparation of the experiment

The Inova control system is used to the hydraulic engine control. The experiment requires:

- Programming the displacement of the hydraulic motor according to the requirements

The Dewe 5000 measuring system is used to record data and video. The experiment requires:

- To set the measuring and recording parameters of the signal from the sensor
- To set the camera recording parameters
- Illuminate the scene, focus the camera, adjust the aperture, position the lights to eliminate glare
- Create a trigger condition to start and stop recording so that data files are not unnecessarily large at a high sampling rate

Experiment procedure:

- Put the impactor into the initial position
- Start recording the image and data
- Accelerate the impactor with the hydraulic engine, carry out the impact

4. Processing the measured data and presenting the results

To display the records from the position sensor, data from the Dewesoft system can be exported in a generally readable format. However, the synchronization with the video will be lost by this procedure.

If the option to analyse the data must be kept, including the synchronous image, identical software must be used, in this case Dewesoft. All settings and possibilities were described in the task 8.

