MODAL TEST AND ANALYSIS

DEWESoft®

SOLUTION USER MANUAL

MODAL TEST AND ANALYSIS V23-1

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2. About this document

2.1 Legend

The following symbols and formats will be used throughout the document.

Important
It gives you important information about the subject.
Please read carefully!

Hint
It gives you a hint or provides additional information about a subject.

Example
Gives you an example of a specific subject.

3. Introduction

3.1 Modal test module and Modal analysis module

The DEWESoft Modal solution is used for analysis of mechanical structures or electrical systems to determine the transfer characteristic (amplitude and phase) over a certain frequency range.

With the small, handy form factor of the DEWESoft instruments (DEWE-43, SIRIUSi) it is also a smart portable solution for technical consultants coping with failure detection. The Modal test module is included in the DSA package (along with other modules e.g. Order Tracking, Torsional vibration, ...).

Let's assume there is a mechanical structure to be analyzed. Where are the resonances? Which frequencies can be problematic and should be avoided? How to measure that and what about the quality of the measurement?

Probably the easiest way is exciting the structure using a modal hammer (force input) and acceleration sensors for the measurement of the response (acceleration output). At first the structure is graphically defined in the geometry editor. Then the points for excitation and response are selected. The test person knocks on the test points while the software collects the data. Next to extracting phase and amplitude, in Analyze mode it is possible to animate the structure for the frequencies of interest. The coherence acts as a measure for the quality. The modal circle provides higher frequency precision and the damping factor.

In Modal Analysis perform the modal parameter Identification (MIF, Curve Fitting , Mode Selection, Stability Diagram, Natural Frequencies, Damping and Mode Shapes).

DEWESoftX Modal Test and Modal Analysis supports both single- and multiple reference configurations.

3.1.1 The differences between Modal Test and Modal Analysis

In short, DewesoftX Modal Test is what you use when performing structural dynamics measurements of objects. DewesoftX Modal Analysis is used after the data acquisition, to estimate high quality modal models.

Modal Analysis uses the results from Modal Test to estimate modal parameters (resonance frequencies, damping ratios and mode shapes)

DewesoftX Modal Test does provide tools to determine modal parameters as well, but these tools only apply for simple structures, having lightly damped and well separated resonance frequencies. DewesoftX Modal Analysis is required to obtain valid modal parameters for complex structures, having multiple resonance frequencies being closely spaced or with heavy damping.

The main features included in DewesoftX Modal Test and Modal Analysis are listed below:

Features	Modal Test	Modal Analysis
FRF (Frequency Response Function)	✔	
CPSD (Cross-power Spectral Density)	✔	
COH (Coherence)	✔	
MIF (Mode Indicator Function)	✔	
Modal Circle	✔	
Modal Geometry Editor and Animation	✔	✔
Stability Diagram		✔
LSCF - Modal Parameter Estimator		✔
AutoMAC		✔
CMIF (Complex Mode Indicator Function)		✔
Synthesized FRFs		✔

More information about Modal Test and Modal Analysis and their differences can be found here and a complete guide to Modal test and analysis can be found here.

3.2 Linear time-invariant systems

At first we have to assume that the methods described here apply to LTI (linear, time-invariant) systems or systems which come close to that. LTI systems, from applied mathematics, which appear in a lot of technical areas, have following characteristics:

- Linearity: the relationship between input and output is a linear map (scaled and summed functions at the input will also exist at the output, but with different scaling factors)
- Time-invariant: whether an input is applied to the system now or any time later, it will be identical

Furthermore, the fundamental giving of evidence in LTI theory is that the system can be characterized entirely by a single function called the system's impulse response. The output of the system is a convolution of the input to the system with the system's impulse response.

3.3 Frequency response function

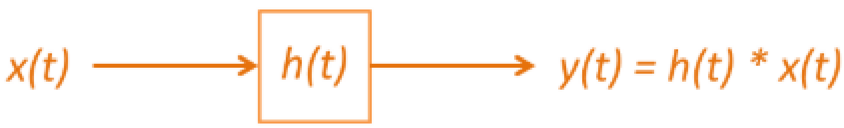
Transfer functions are widely used in the analysis of systems, the main types are

- **mechanical** → excite the structure with a modal hammer or shaker (measure force), measure response with accelerometers (acceleration)
- **electrical** → apply a voltage to the circuit on the input, measure back the voltage on the output

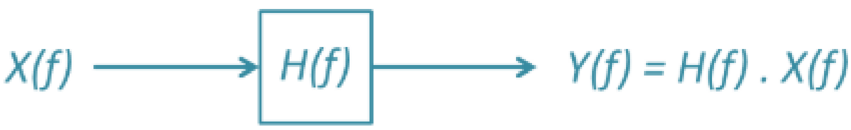
In mechanical structures for example, when the transfer characteristic is known, this will show dangerous resonances. The frequency range, where the stress to the material is too high, has to be avoided, e.g. by specifying a limited operating range. The simplified process works like that: an input signal is applied to the system and the output signal is measured. The division of response to excitation basically gives the transfer function.

$$H(\omega) = \frac{Y(\omega)}{X(\omega)}$$

In time-domain this is described in the following way:



Laplace transformation leads to the result in frequency domain:



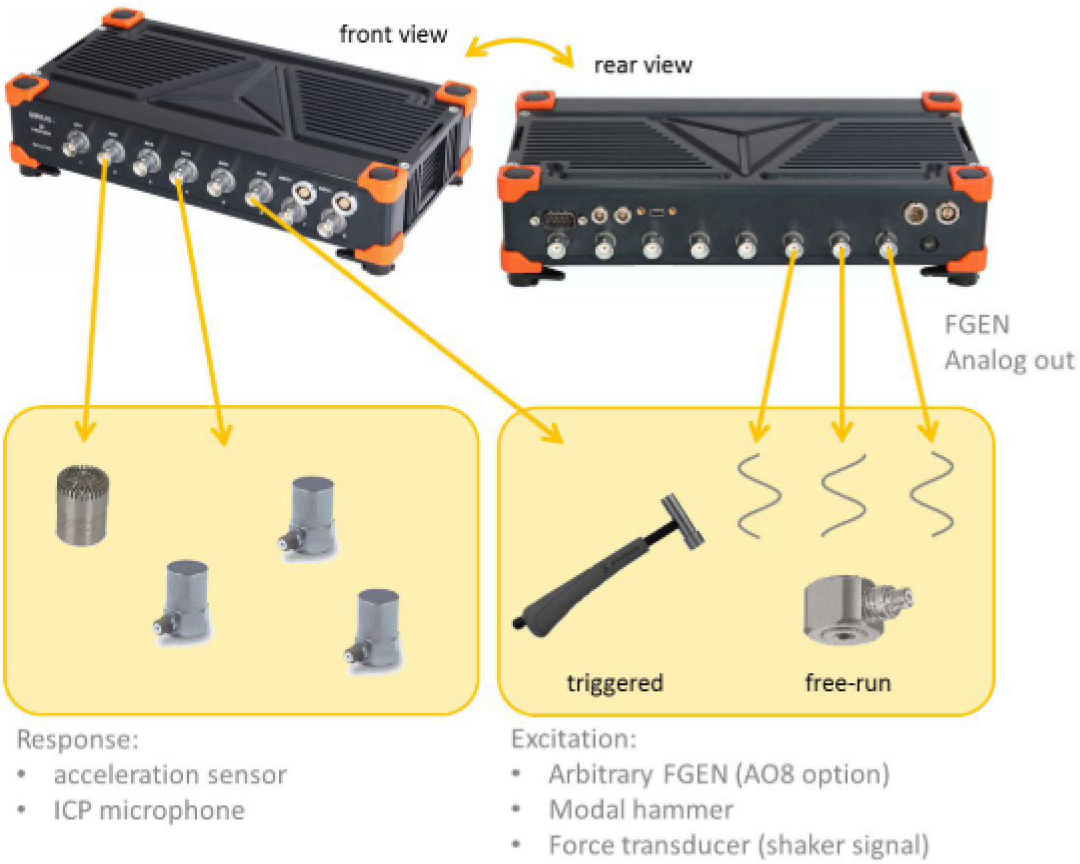
DEWESoft utilizes H1 and H2 parameter estimation methods.

$$H1(\omega) = \frac{Sxy(\omega)}{Sxx(\omega)}$$

Sxy(ω) = cross spectrum between excitation and response
Sxx(ω) = auto spectrum of excitation

3.4 System overview

In most of the cases acceleration sensors, microphones, modal hammers or other force transducers are used for analog input. If they are e.g. voltage or IEPE/ICP type, they are connected to the SIRIUS ACC amplifier, or DEWE-43 with DSI-ACC adapter. When analog output is needed (shaker), the AO option (8 channels BNC on rear side of SIRIUS instrument) provides a full-grown arbitrary function generator.



3.5 Mounting of the Test Structure

When performing modal testing the DUT must be able to vibrate dynamically in ways that will reveal all and correct natural frequencies and mode shapes of the structure.
To pursue free vibration patterns, or similar vibration patterns as expected when the structure is operating in real life, materials like rubber bands, elastic wires, foam pads, and other materials providing a soft elastic system are often used to hang or place the structure on at the locations the structure is designed to be fixed.

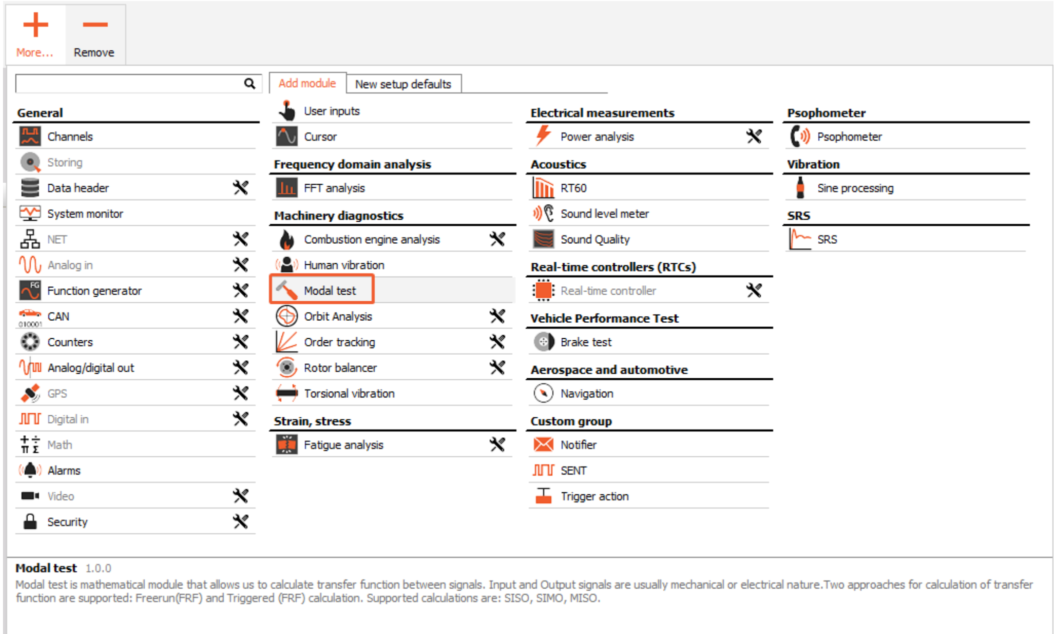
If e.g. the test structure is fixated at some positions under test that are going to vibrate freely when the test structure is operating in real life, then the measured dynamic properties will not fully relate to the real life usage of the structure - since adding stiffness to the structure will shift the frequencies upwards, and it might also cause some mode shapes to be undetected.

Rigid body motion
Rigid motion, or rigid body modes, are vibrations of the whole DUT as a rigid object, and do not provide information of the structural dynamic properties of the DUT (the flexible modes). Such rigid body modes are related to the selected support configuration.
Depending on how the DUT is mounted the rigid body modes might affect the flexible modes of the structure in an unacceptable manner. The impact of the rigid modes on the flexible modes depends on how close in frequency the rigid modes are to some flexible modes, and on what is determined to be an acceptable accuracy of the measurements.
A rule of thumb is often to accept the modal data if there is greater than a 10:1 frequency ratio between the rigid body modes and the flexible modes, e.g. last rigid mode at 1 Hz and first flexible mode at 10 Hz.

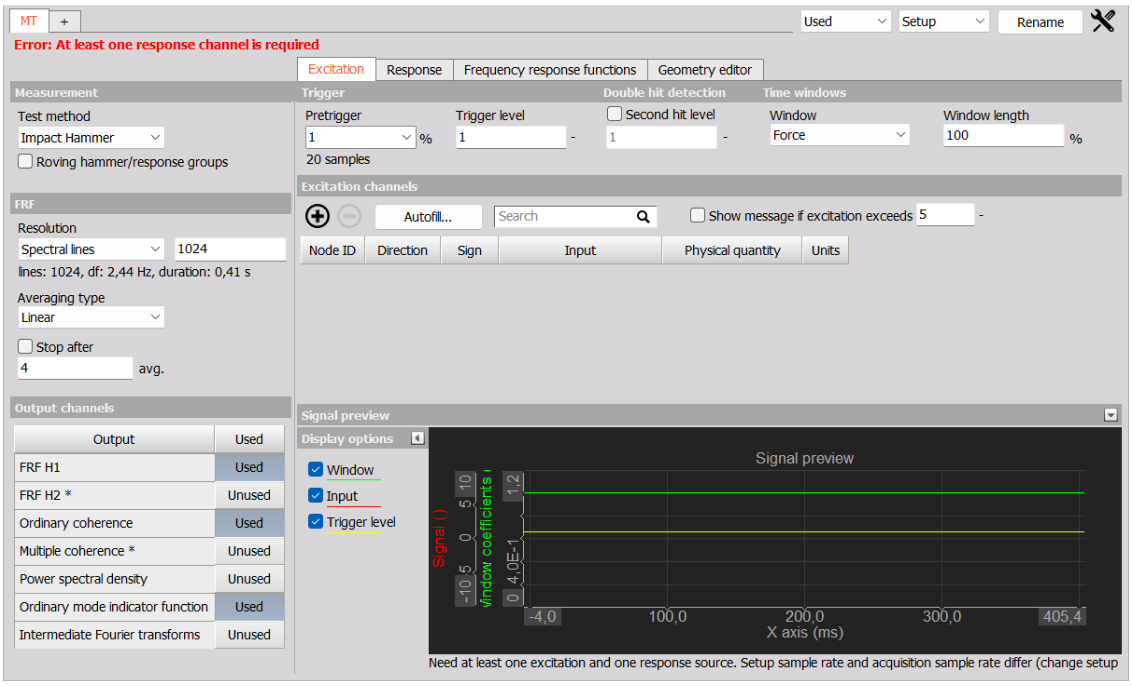
4. Modal Test Setup and Operation modes

4.1 Adding Modal test module

First, adding the Modal test module is done similarly as for other modules: Under '+ More...' you find and click on the module and it will be added to the setup.



Application specific modules available to add to the setup.

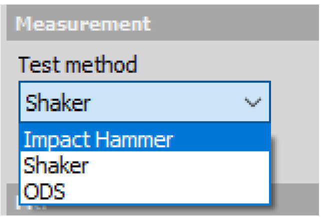


After adding the Modal test module the MT setup page will appear as shown above.

4.2 Test methods

The description of the channel setup and the parameters for the different test methods are split into the chapters: 4.1 Impact hammer, 4.2 Shaker, 4.3 Spectral ODS and 14. Time ODS.

Depending on the application DEWESoft offers three different types measurement test methods:



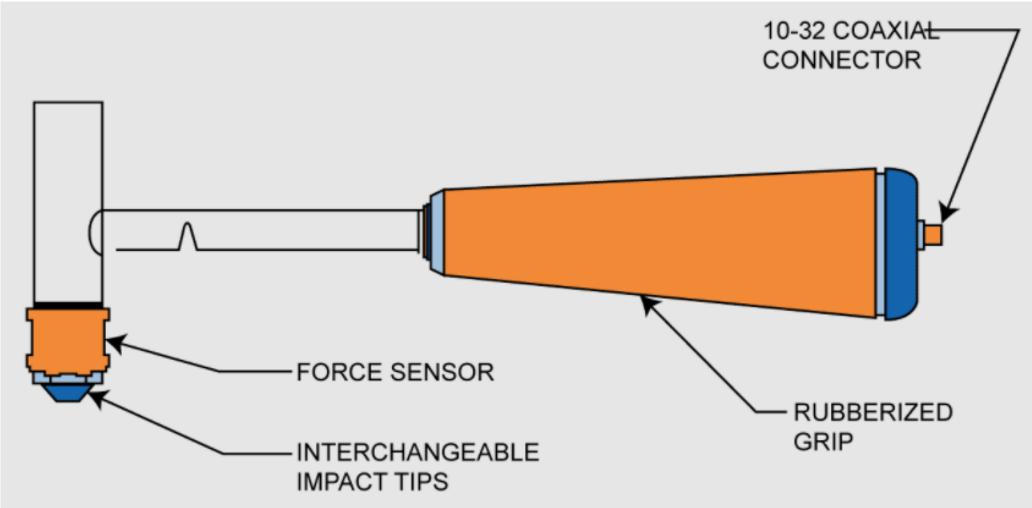
Modal Test methods.

- **Impact hammer**: For excitation an impulse is used (=wide frequency spectrum), e.g. modal hammer; triggered acquisition
- **Shaker**: The structure is excited e.g. with a shaker (or the engine rpm is varied), which sweeps through the frequencies (e.g. 10...1000 Hz)
- **ODS**: operational deflection shapes, only response of the structure is measured. Spectral ODS is configured in the Modal test setup plugin, while Time ODS is configured in a separate Time ODS setup plugin.

As the channel setup is different between the test methods they will be explained separately, along with practical examples.

4.3 Impact hammer

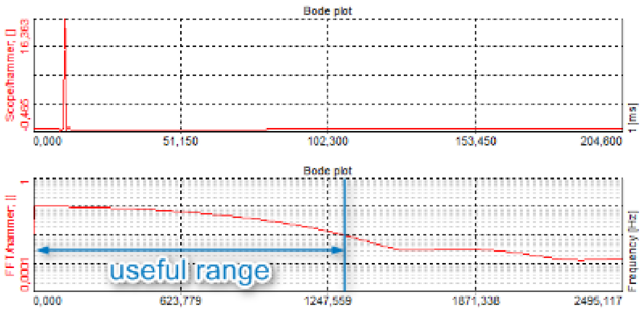
The easiest test consists of the modal hammer, which is used for exciting the structure with a short impulse (= wide frequency spectrum) and an acceleration sensor measuring the response. The hammer has a force sensor integrated in the tip, the tip ends are interchangeable. For bigger structures there are big hammers available with more mass to generate a distinct amplitude.



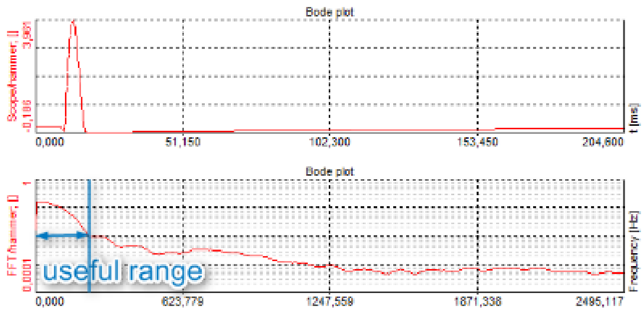
Sketch of a typical modal impact hammer.

HINT:
Please keep in mind that a hard tip generates a wider excitation spectrum, therefore you will get a better result (coherence) for the higher frequencies.

The two pictures below show the comparison. The scopes on top show time-domain, FFTs below show frequency domain (same scaling).



hard tip (low damping)

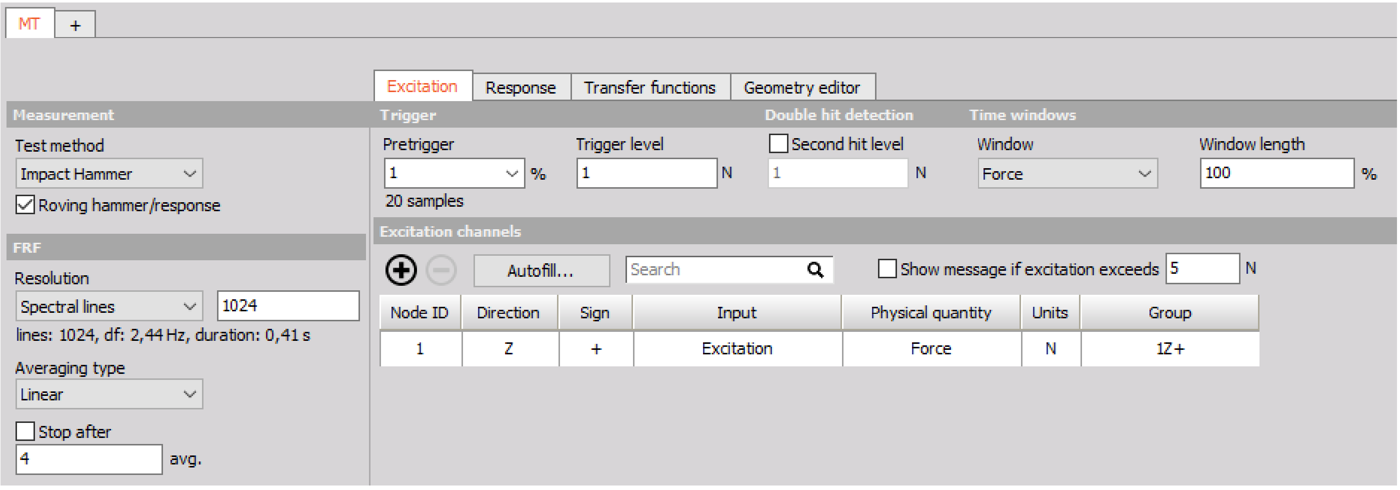


soft tip (high damping)

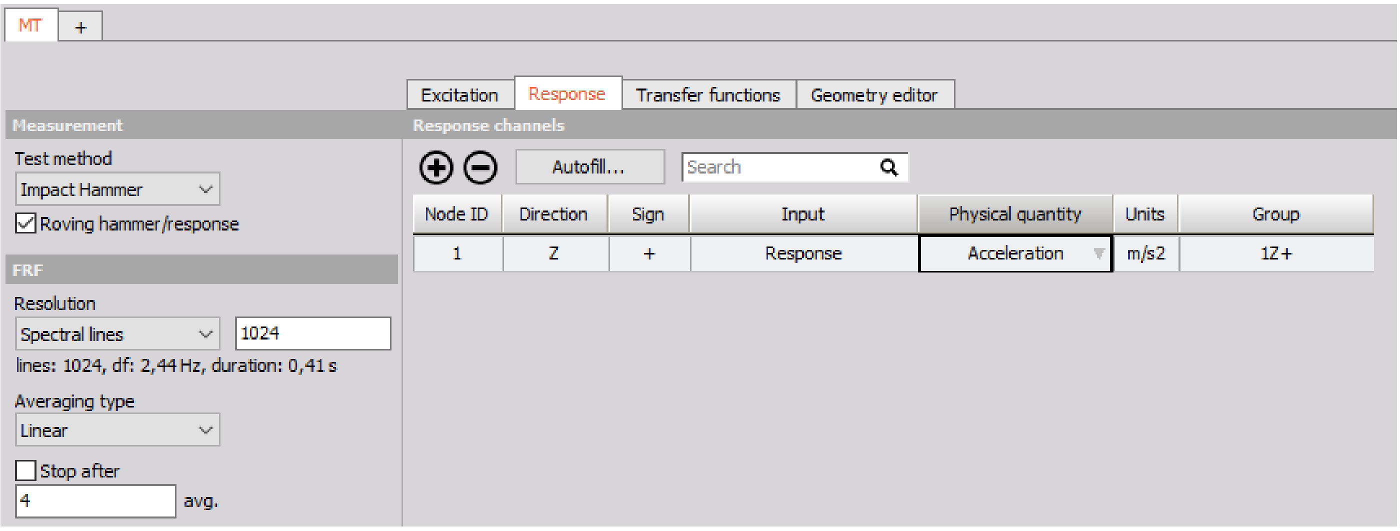
On the other hand, with a hard tip double-hits appear more frequently.

When you have set the calculation type to “Impact hammer”, the setup looks like shown below.

Under the Excitation tab specify the excitation channels (modal hammer), in the Response tab set the response channels (acceleration sensors). For the following examples we named the two analog channels “Excitation” and “Response”.

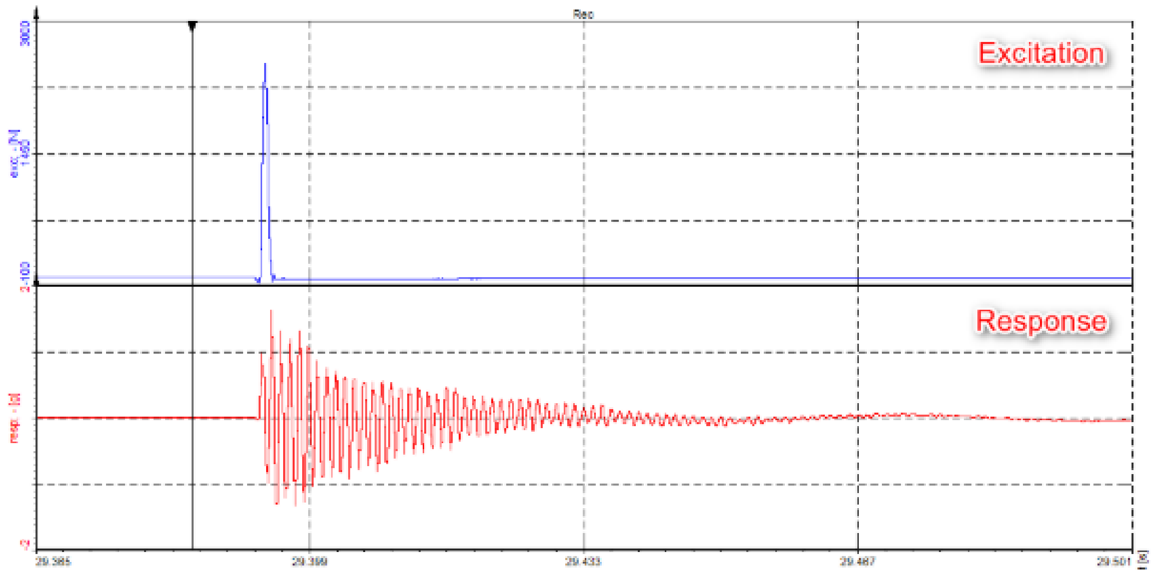


Modal Test setup for Impact hammer testing, showing the Excitation tab.



Modal Test setup for Impact hammer testing, showing the Response tab.

Let's do a short measurement to explain all the parameters. The structure is hit once and the signals are measured.

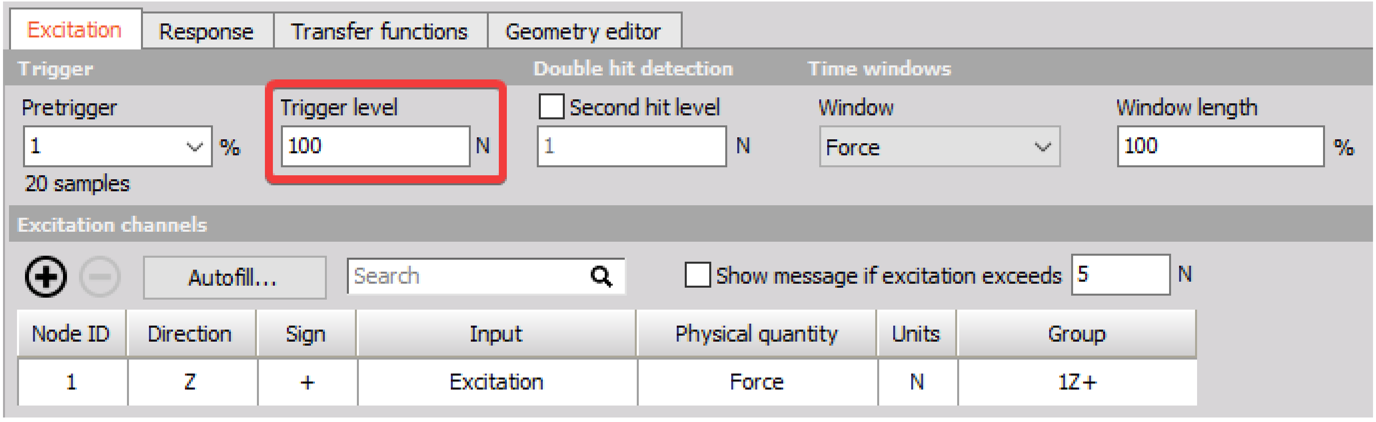


Transient impact excitation signal (blue). Ringing structural response (red).

The hammer signal (upper, blue line) shows a clean shock impact with about 2500 N peak and high damping, while the response (lower, red line) starts ringing and smoothly fades out.

Trigger level

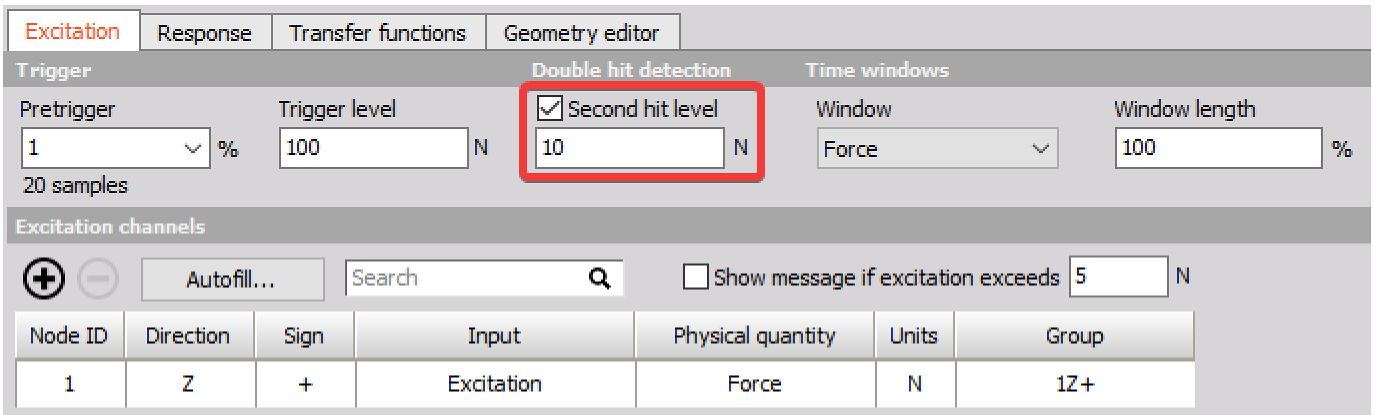
The Modal test module needs a start criteria in triggered mode, therefore we specify a trigger level of e.g. 100 N. Each time the input signal overshoots the trigger level, the FRF calculation (FFT window) will start



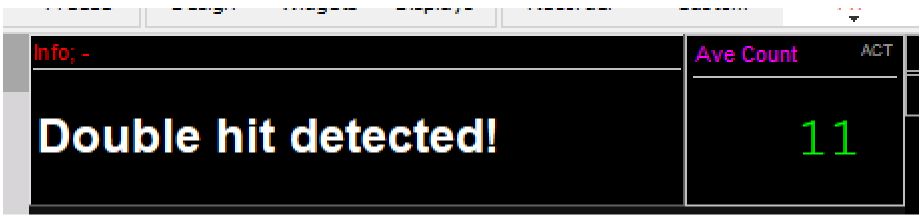
Impact hammer Trigger level settings.

Second hit level

However, when the input signal shows multiple impulses after one hit (so called "double hit"), DEWESoft can identify this if you specify a second hit level. When the signal crosses the second-hit-level shortly after the trigger event, you will get a warning message and can repeat this point.



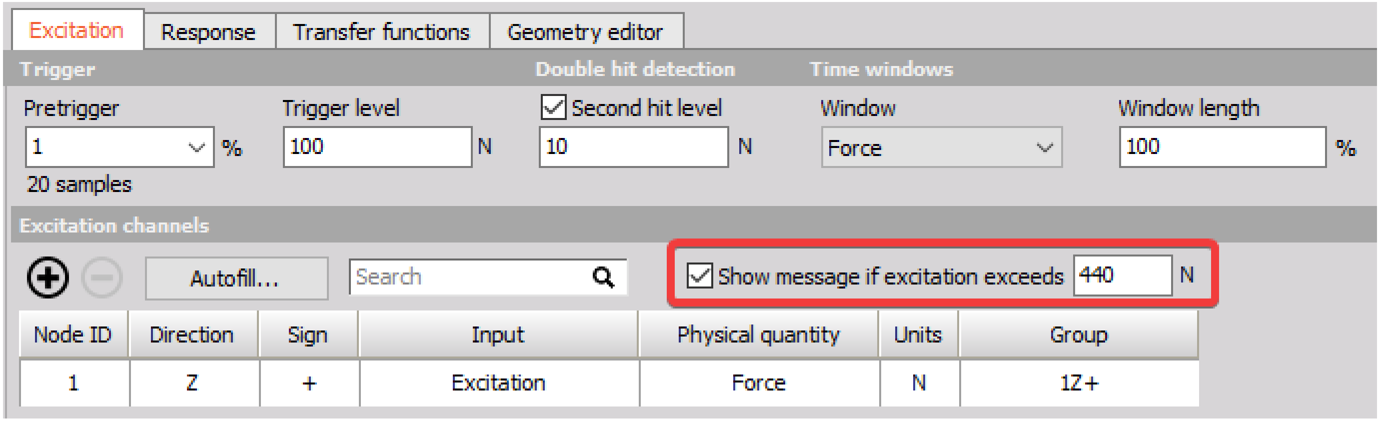
Double hit detection level settings.



Double hit status response while performing the measurement.

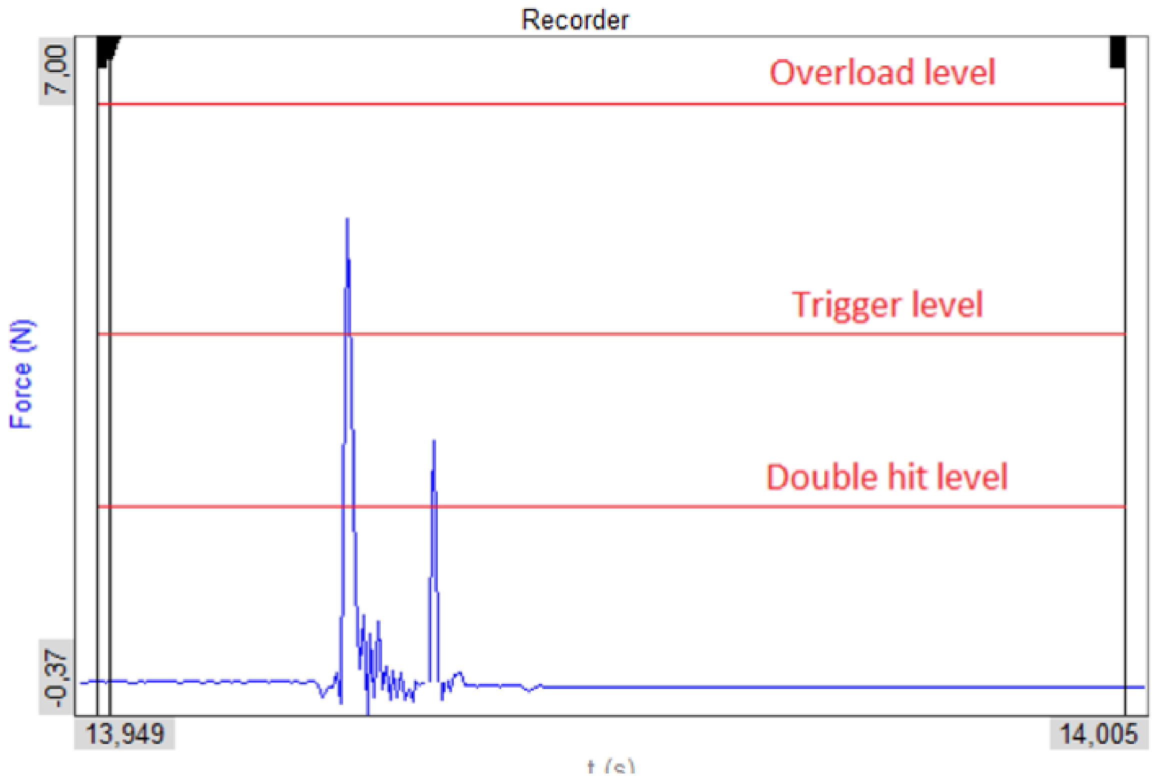
Overload level

You can also enable that a warning will be displayed, if the hammer impact is exceeding a certain overload level (when the hit was too strong).



Overload detection settings.

The following picture summarizes the different trigger level options.



Example of proper levels set for a specific test scenario. Overload is only hit if it is too high and double hit level is only detected if the second bounce-hit is relatively high.

After configuring the trigger condition, we should ensure that the FRF calculation covers the whole signal to get a good result.

Window length

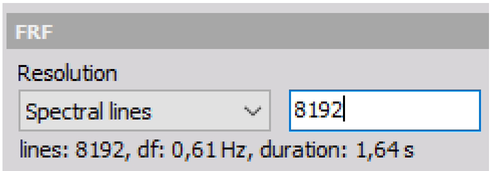
Let's assume the sample rate of our example is 10 000 Hz and we have adjusted 8192 lines in the Modal test setup.

According to Nyquist we can only measure up to half of the sample rate (5000 Hz), or the other way round, we need at least 2 samples per frequency line. So, our frequency resolution is:

Df = 10 000 Hz / (8192 lines x 2) = **0,61 Hz**.

The whole FFT window calculation time (FFT block length) is

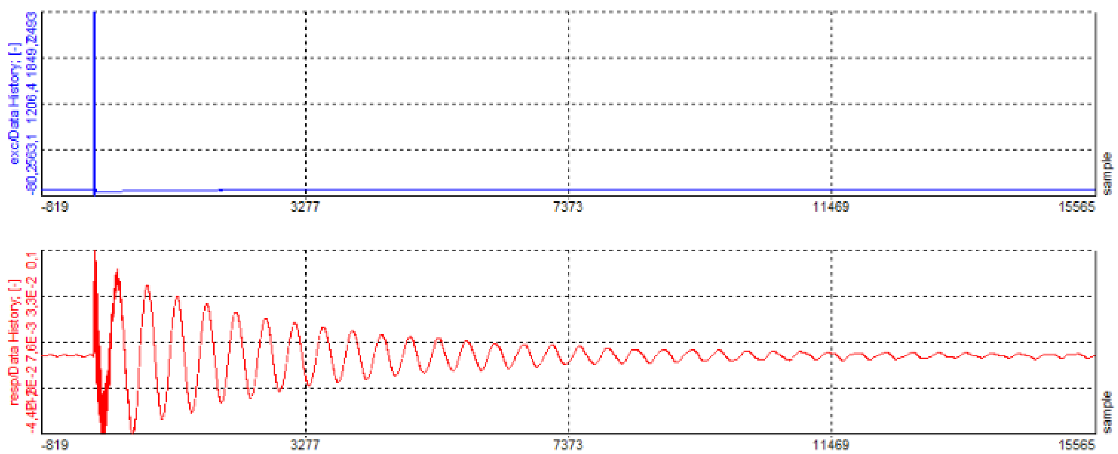
t = 1 / Df = 1 / 0,61 = **1,638 s**.



Spectral resolution settings. All spectral modal test results will be configured after the user-defined Resolution setting.

Below you see the cut out data section of excitation and response signal, which covers pretty much the whole signal. Note, that the x-axis is scaled in samples (from -819 to 15565, which gives a total 16 384 samples).

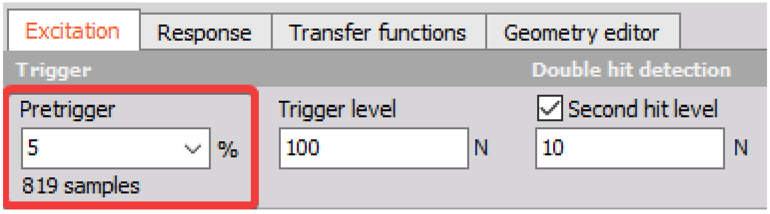
16 384 samples * (1/10 000 Hz) = **1,64 s**.



Blue: Transient input. Red: Ringing response output with a ringing duration that indicates that a relatively long Time block should be used to include the full response.

Pretrigger

Pretrigger is the amount of “buffer time” measured before the trigger level was crossed. The pretrigger time is set to 1 % (of the FFT block length) by default. From the screenshot above a 5 % pre-trigger is used and you can see that 5% of 16 384 samples is 819 samples, which equals t_{pre} = 819 * (1/10 000 Hz) = 81,9 ms. At sample 0 the trigger occurs.



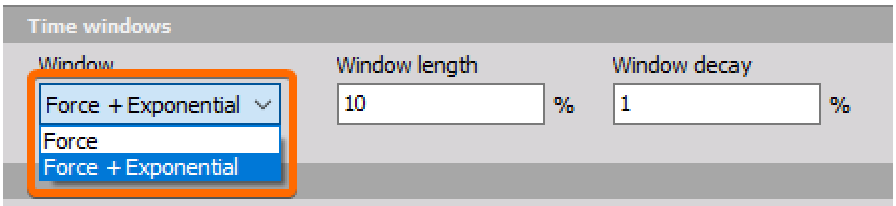
Pre-trigger works like a negative trigger delay, where the Time block to use will start some samples before the actual trigger was detected.

Pretrigger must be used to reduce leakage and to avoid distorted FRFs. Without using the pretrigger, you can lose the initial part of the input signal.

Time windows

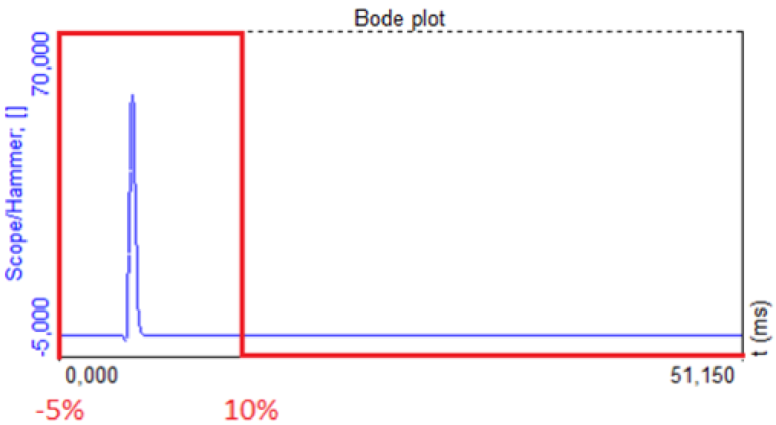
You can separately adjust the window length of excitation and response (it's like cutting out the interesting segments of the graph above) in order to reduce the influence of noise appearing after the event of interest.

The windowing can be set to **Force** or **Force + Exponential**.



For triggered modal testing suitable window types can be selected.

Force: will apply a rectangular window in excitation channels (in selected %) and rectangular window (100%) to response channels



Force window illustration. A rectangular window with a limited length relative to the Block duration.

Force + Exponential: will apply an exponential window on the excitation channels with a length set by the Window length. After the Window length the exponential window drops to zero. The response channels will get an exponential window over the full FFT block length, T. Both for the excitation and response channels the Window decay percentage is relative to T.

'Force + Exponential' is commonly used for impact testing since it both reduces noise on the excitation and response channels, and keeps equal decay ratios between excitation and response channels inside the defined Window length, which avoids the need for additional window corrections.

An illustration of Force, Force + Exponential, and Exponential windows are shown below:

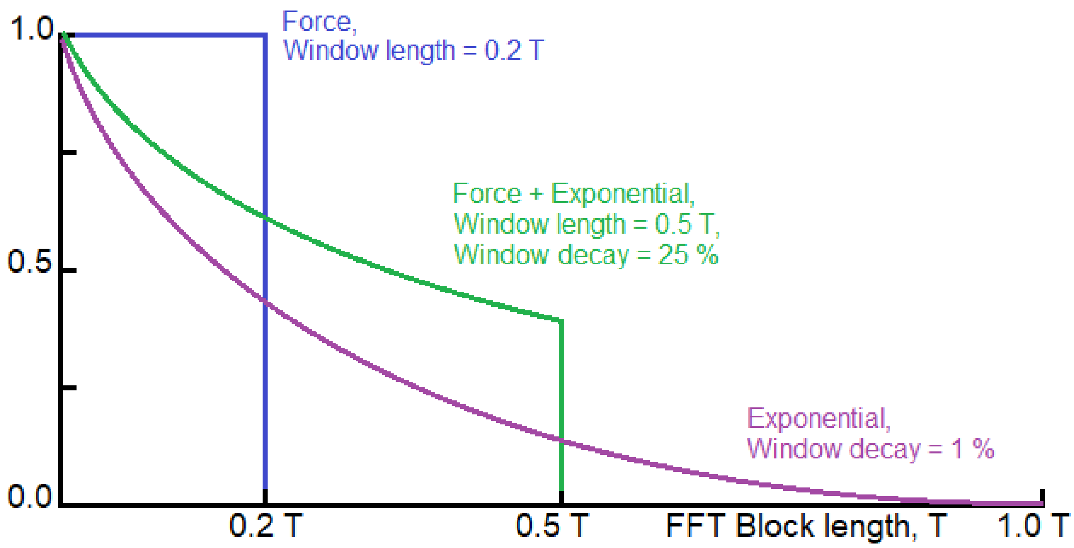
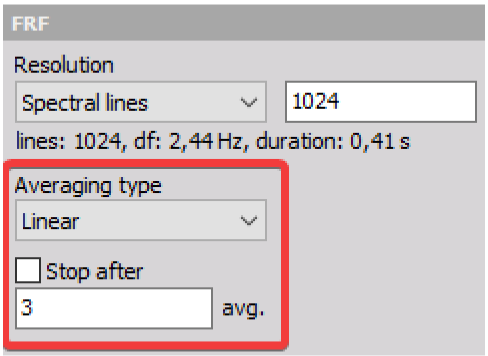


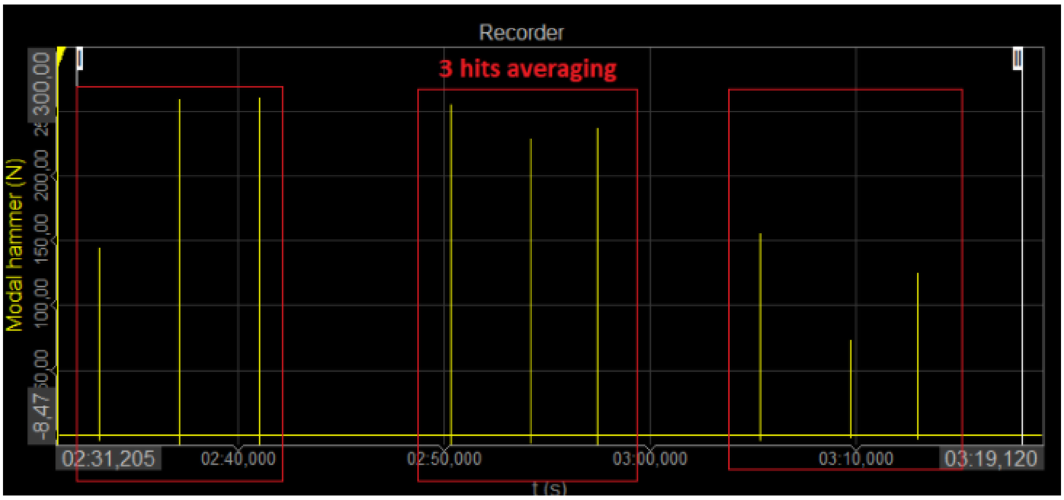
Illustration of transient window types. Blue: Force. Purple: Exponential. Green: Force + Exponential.

Averaging of hits

The result can be improved by averaging the excitation and response spectra over a number of impacts. Therefore the first e.g. 3 hits will be recognized and taken into calculation, then you move on to the next point. If '**Stop after**' is not selected, you can make as many hits as you want to average for each point.



Averaging settings.

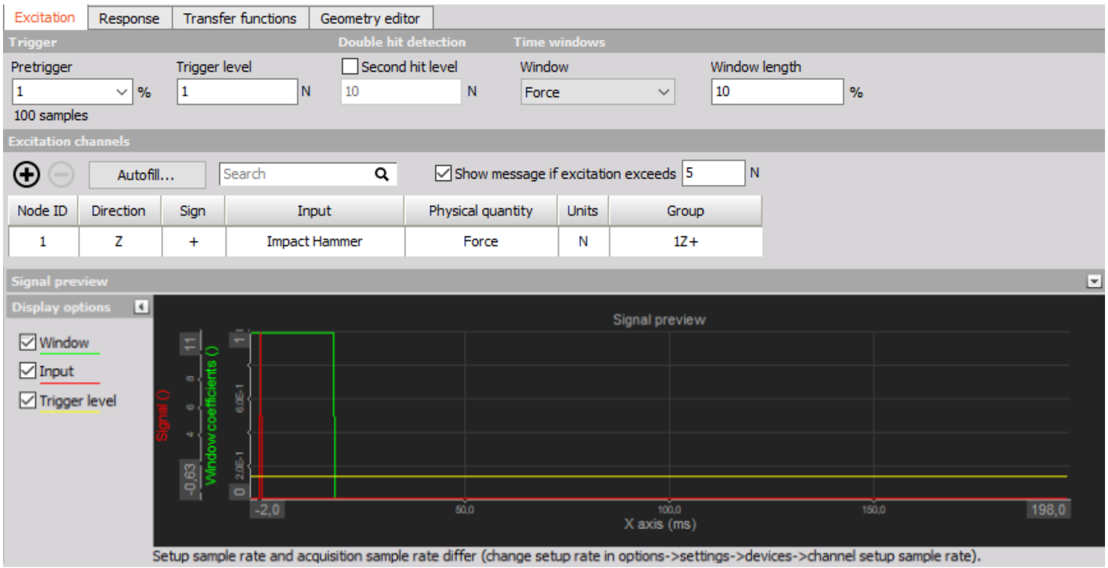


Showing three DOFs hit three times each. Each group of three hits will be averaged together to one result per DOF.

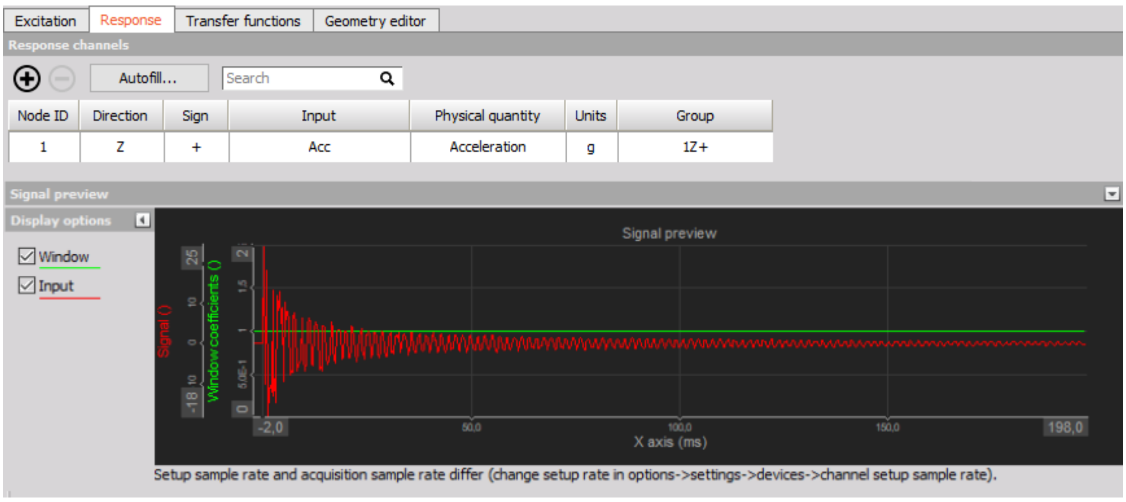
4.3.1 Signal preview

Directly in the Modal test module we offer users to be able to see the preview of excitation and response channels.

With this preview the user can correctly set the trigger level, second hit level and windowing.



Signal preview helps with quickly determining suitable values for multiple parameter settings. Here shown for Excitation settings.



Signal preview helps with quickly determining suitable values for multiple parameter settings. Here shown for Response settings.

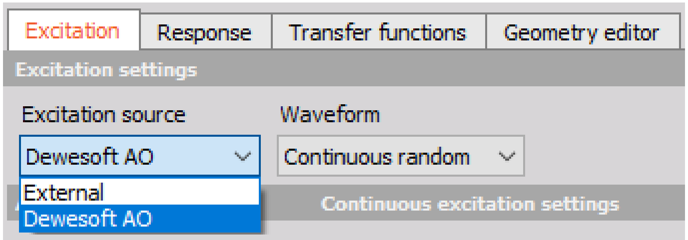
Important:

Please note that the preview depends on the setup sample rate and not acquisition sample rate. They might differ depending on the settings in Settings -> Devices -> Channel setup sample rate.

4.4 Shaker

Modal shakers are types of vibration shakers used to excite large or complex structures and to achieve high-quality modal data. In comparison to modal hammers, modal shakers have the ability to excite the structure in a broader frequency range, and with many different signal types, best suited for different structures and ideal for accurate test results.

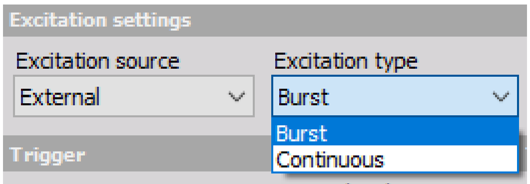
In the Modal test module, shakers can be controlled externally or with Dewesoft AO channels.



For the Shaker Test method both External and internally generated Excitation source signals are supported.

4.4.1 External excitation source

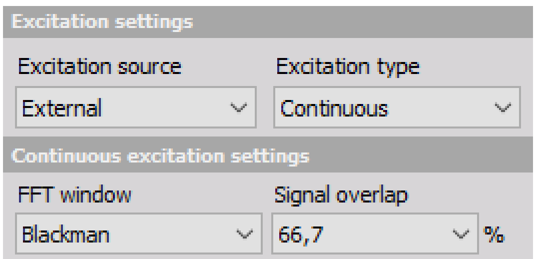
If the shaker is externally controlled, we offer users to have burst mode (triggered acquisition) or continuous mode (free-run acquisition).



External shaker excitation types. Burst relies on trigger settings - Continuous does not.

4.4.1.1 Continuous

In Continuous mode spectra are calculated continuously as data are acquired throughout the measurement. A list of time weighting FFT windows for continuous signals are supported, and the calculated spectra can be set to overlap in time by specifying the Signal overlap parameter.

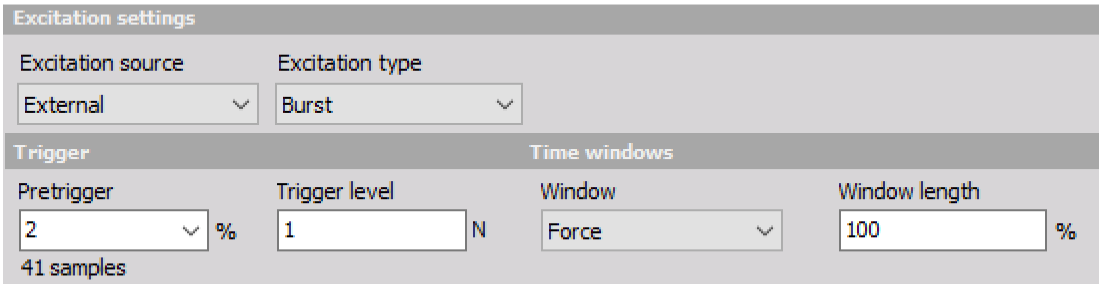


Continuous external excitation settings.

The calculation runs to the end of the measurement, but it can also be stopped automatically after a user-defined number of spectra by Checking on the 'Stop after' parameter under FRF settings, and specifying a number of averages.

4.4.1.2 Burst

In Burst mode the calculation of each spectrum is triggered by the externally controlled excitation signal. When the excitation input signal exceeds the Trigger level a new spectrum will be calculated. Depending on the ramp-up burst time, a Pretrigger can be adjusted to ensure the FFT block of time samples, used for a spectrum, includes the entire burst.

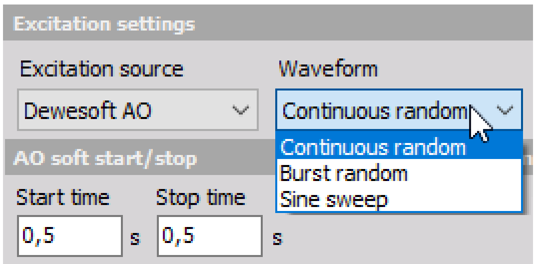


External Burst Excitation settings.

Time window functions for burst random signals are supported together with related user-defined window parameters. With triggered spectrum calculation Signal overlap is disabled since it is controlled by the trigger.

4.4.2 Dewesoft AO excitation source

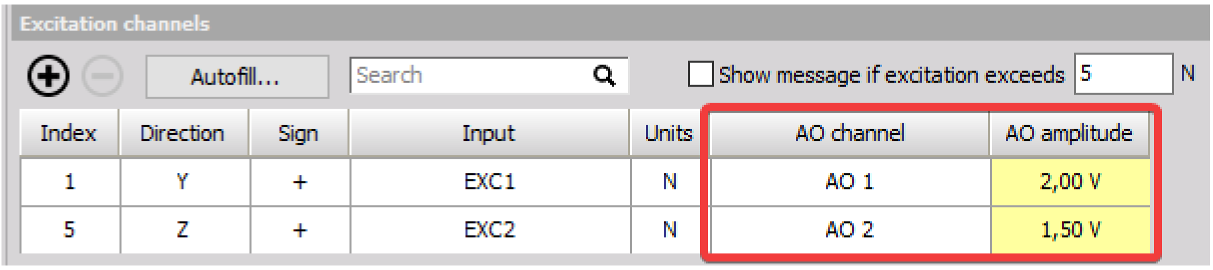
If the shaker is controlled with Dewesoft AO, we support Continuous random, Burst random and Sine sweep generator output excitation signals. AO is an abbreviation for Analog Output.
All the settings for the function generator can be done directly in the Modal test setup.



Dewesoft AO (HW Analog Out) supported waveform types.

For all Waveform types the AO soft start and soft stop times can be set. The soft start/stop times define the duration of half-sine leading and trailing gain tapers. The measurements will be calculated after the leading taper and before the trailing taper, except for triggered calculations when using Burst random.

In the Excitation channels table the Dewesoft AO channels to use must be selected, and their output voltage amplitudes must be set.



DEWESoft AO excitation channel settings. Which Analog Output should be used and which amplitude should it provide.

4.4.2.1 Continuous random

By selecting the Waveform type Continuous random, AO channels will output continuous random noise. The random noise will have a frequency Bandwidth equal to the Nyquist f_N of the DAQ sample rate f_S, given by:

$$f_N = f_S / 2$$

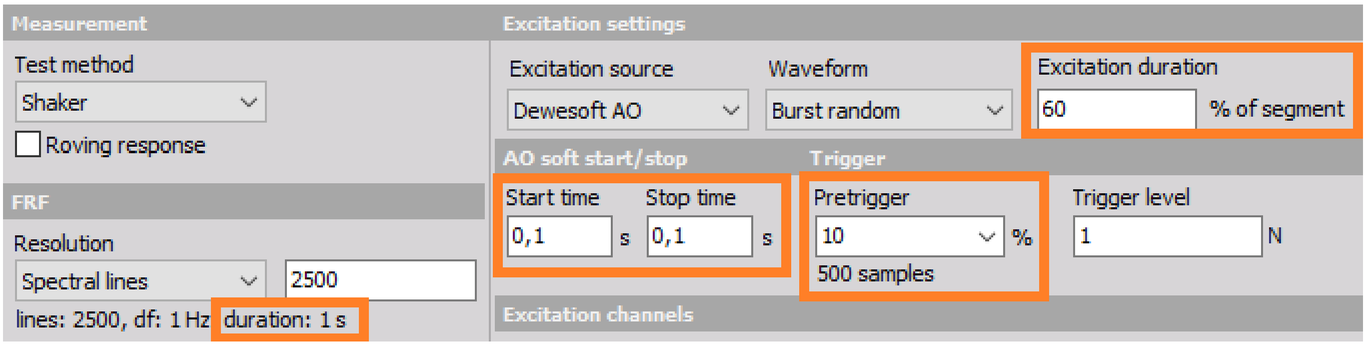
Other settings like the FFT window and Signal overlap follow the description in the section 4.2.1.1 Continuous.

4.4.2.2 Burst random

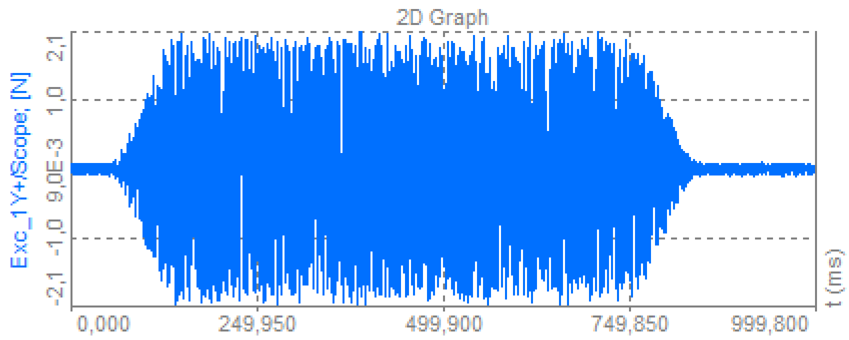
With Burst random Waveform type, the AO channels will output bursts of random signals with a user-defined burst length. The burst length, between the AO soft start and stop times, is set by the Excitation duration parameter. The excitation duration is specified in percent of the FFT time block length used for each spectrum.

Burst duration is defined relative to the FRF (spectrum) time block duration.

Note:
For minimum spectral leakage, remember to limit the Excitation duration enough to have room for the AO soft start/stop times in the FFT time blocks. Also, make sure the Pretrigger is set such that the FFT time block includes the entire burst - from the beginning of AO soft start to the end of the AO soft stop.



Example of ideal DEWESoft AO Burst random settings, where the full burst including the leading and trailing tapers are captured in the time block duration, that are used to calculate the spectral results.



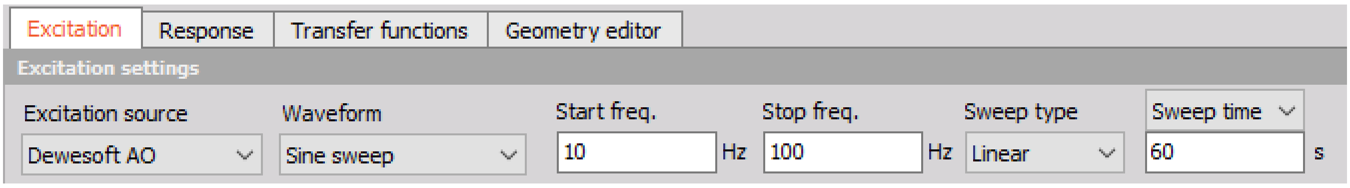
The time block data used for the FFT processing which provides all derived spectral modal results.

Like described in the section 4.2.2.1 Continuous random, the bursts of random noise will have a bandwidth equal to Nyquist f_N of the DAQ sample rate.

For Burst random the window function is always rectangular/uniform.

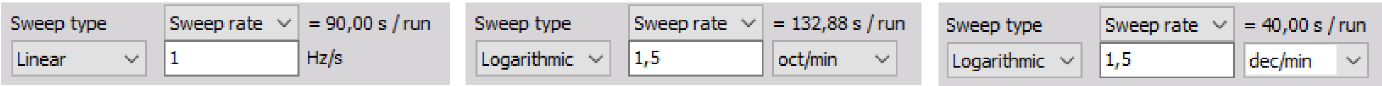
4.4.2.3 Sine sweep

The Sine sweep waveform outputs a sinusoidal signal that sweeps in frequency from Star freq. to Stop freq. over a specified Sweep time or with a specified Sweep rate. The frequency sweeping will begin after the AO soft start time and end before the AO soft stop time.



DEWESoft AO Sine sweep excitation waveform type settings.

The Sweep type can be either Linear or Logarithmic sweeping over the frequency range.
When the sweep duration is set to be defined by a Sweep rate, the rate will be set based on the selected Sweep type.



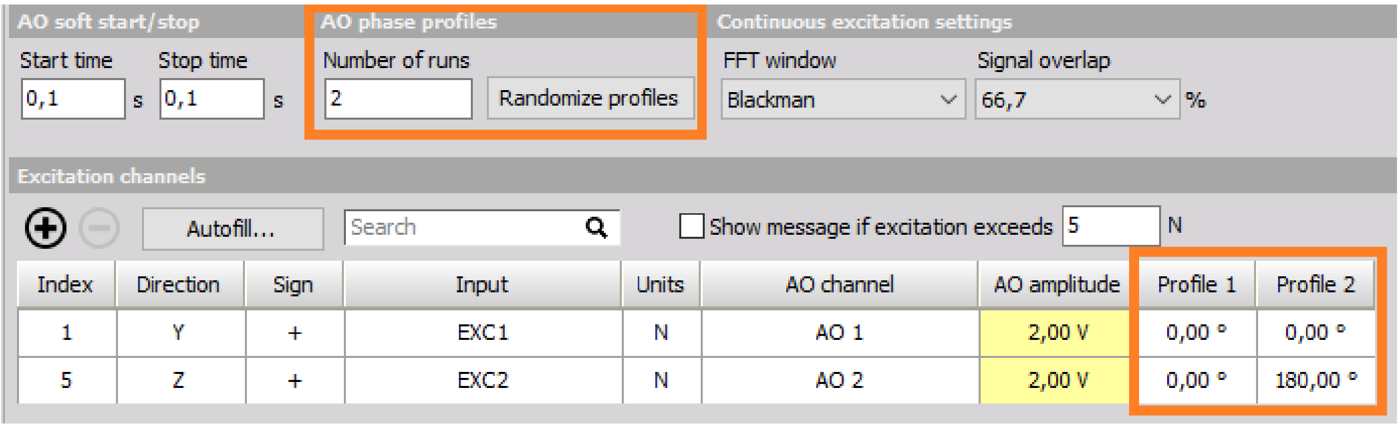
DEWESoft AO Sine sweep has settings to control both a Linear and a Logarithmic frequency sweep. Octave is a factor of 2. Decade is a factor of 10.

When using Sine sweep with multiple shakers, multiple sinusoidal sweeps have to be measured to be able to un-correlate the multiple input excitation signals. To be able to distinguish between the multiple excitation signals , the excitation pattern has to be different between the sweep runs. In DewesoftX, this is managed by changing the phase pattern between sweep runs for the AO channels.

Each sweep will have a phase profile containing the phase for each AO channel. The profiles can be set randomly by pressing the button Randomize profiles, or it can be set by the user in the Excitation channels table.

In order to un-correlate the excitation signals, at least the same number of sweep runs as the number of included AO channels must be used. The multiple phase profiles should be as different as possible to get best results. For example using two AO channels the optimal phase profiles are 0° and 0° for run 1, and 0° and 180° for run 2.

The measurements are averaged over all sweep runs, hereby measured data from all phase profiles are used for the spectral results.



Phase pattern settings is a part of configuring DEWESoft AO Sine sweep with multiple Excitation AO channels.

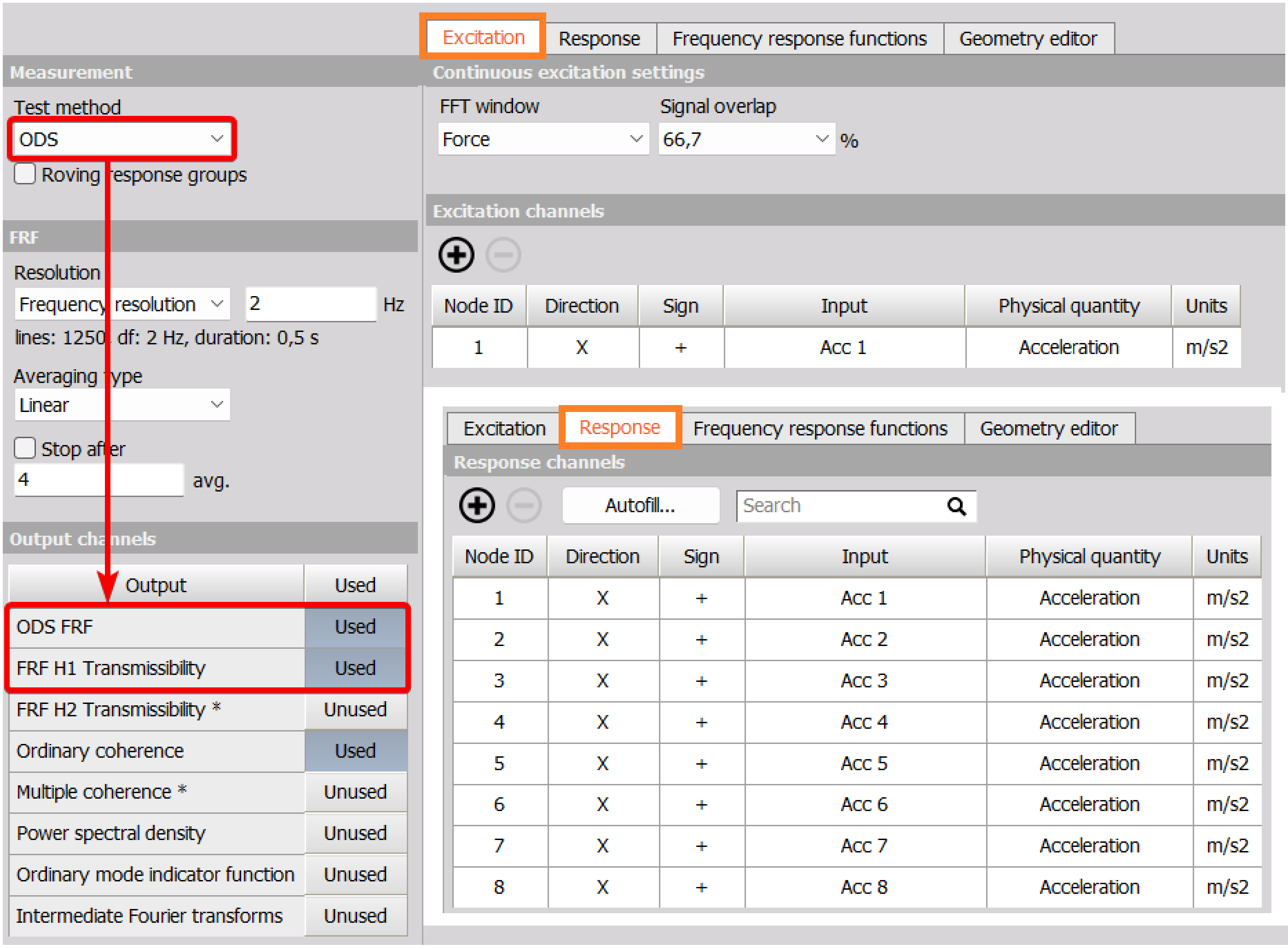
No phase profiles need to be configured for the random waveform types, since the excitation patterns between AO channels already change by the independent noise signals

.

4.5 Spectral ODS (Operating Deflection Shapes)

Operating Deflection Shapes (ODS) is a simple way to do dynamic analysis and see how a machine or a structure moves within its operational conditions. ODS tests have no applied artificial forces, but are measurements only of the structure's own vibrations while in operation. ODS measurements hereby also only measure output response vibration signals and not input force signals.

When performing Spectral ODS, one of the accelerometers is selected as a reference (Excitation) channel, while all accelerometers are selected as Response channels.



One of the response (output) channels is selected also as the excitation (input) channel, which will be used as phase reference to all other response channels. For the Test method ODS the main Output results are the ODS FRFs and the Transmissibilities.

When the Test method ODS is selected then the Output channel types change to comply with Spectral ODS measurements.

With the Test method set to ODS, the main output result from Frequency ODS testing is the **absolute ODS** function, named '**ODS FRF**'. The ODS FRF function is also known as 'phase-assigned spectrum',

'PAS', or 'phase-referenced spectrum'. ODS FRFs contain the magnitude of the response channel while having the phase between that channel and the reference response channel.
The **relative ODS** outputs are shown as the **FRF H1 and H2 Transmissibilities**, which have a magnitude related to the ratio between the response and the reference response.

For example, when having a transmissibility function between DOF A and DOF B then the response at DOF B can be calculated from the measured response at DOF A using the transmissibility function.

The reference channel(s) should, as always for modal testing, be the channel(s) that reveals the most structural deflection shapes. If not all deflection shapes can be detected at a single reference location, then multiple reference locations must be used if all deflection shapes should be analyzed.

Since no input force data is measured while performing ODS testing, you also do not have the normal input/output relationship as you have with Impact hammer or Shaker testing.
This makes ODS measurements unsuitable for determination of damping factors and mode shapes . ODS testing is instead mainly used for looking at deflection shapes.
The deflection shapes may include natural (resonance) responses if excited by the operation condition, but also forced (operation) responses which are not resonances.

4.6 Transfer functions tab

The transfer functions tab gives an overview of which transfer functions that will be calculated.
For large test setups involving many sensor locations and multiple references the full set of transfer functions can be big. If not all transfer functions are required while performing measurements they can be toggled from '**Used**' to '**Unused**' to increase the performance.
In Analyze mode, when doing post-analysis, the 'Unused' transfer functions can be toggled back to 'Used' and recalculations can be done based on the acquired time data.

Excitation | Response | Transfer functions | Geometry editor

Transfer functions

Responses \ Excitations		1Z+ (group 1Z+)
		Used
1Z+ (group 1Z+)	Used	1Z+/1Z+
2Z+ (group 2Z+)	Used	2Z+/1Z+
3Z+ (group 3Z+)	Unused	3Z+/1Z+

Table showing which of the Excitation and Response channels that are used for calculating output functions.

4.7 Geometry editor tab

Under the Geometry editor tab you can create or import a geometry that relates to the test. The geometry is mapped to the channels via the Node IDs. After connecting all nodes to channels the geometry can animate mode shapes and defection shapes depending on the used Test method.

For more information about how to use the Geometry editor please look at section 6.6 Modal geometry widget.

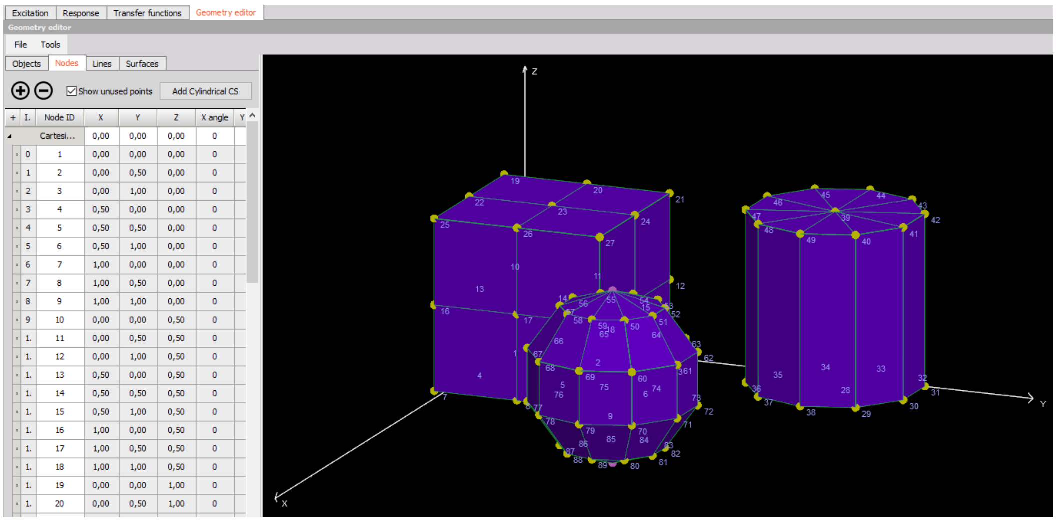
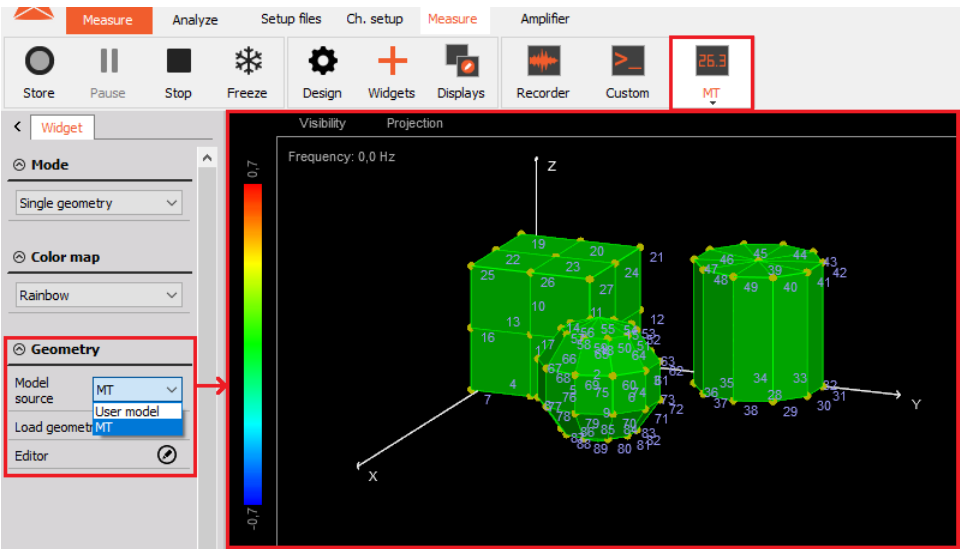


Illustration of the Modal geometry editor tab under the Modal Test module.

The created or imported geometry will automatically be applied to the related Measure display MT template.



The pre-defined Modal Test display templates will use the defined geometry from the Geometry editor tab when the Model source is set to MT.

5. How to perform Modal test

When the test preparations are done the modal test is ready to start. For EMA testing, depending on the test situation it might have been chosen to use one or multiple modal exciters and one or multiple response sensors. These different test configurations are grouped into the sections 'Single-reference Modal Tests' and 'Multi-reference Modal Tests'.

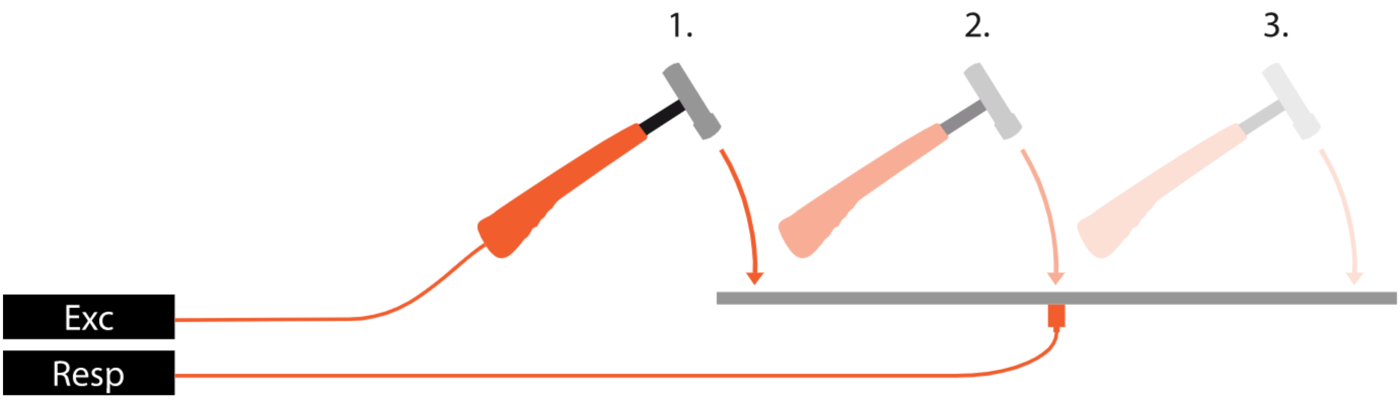
5.1 Single reference modal test

In some test cases, it is sufficient to extract the modal model from measurement data with only one reference DOF.

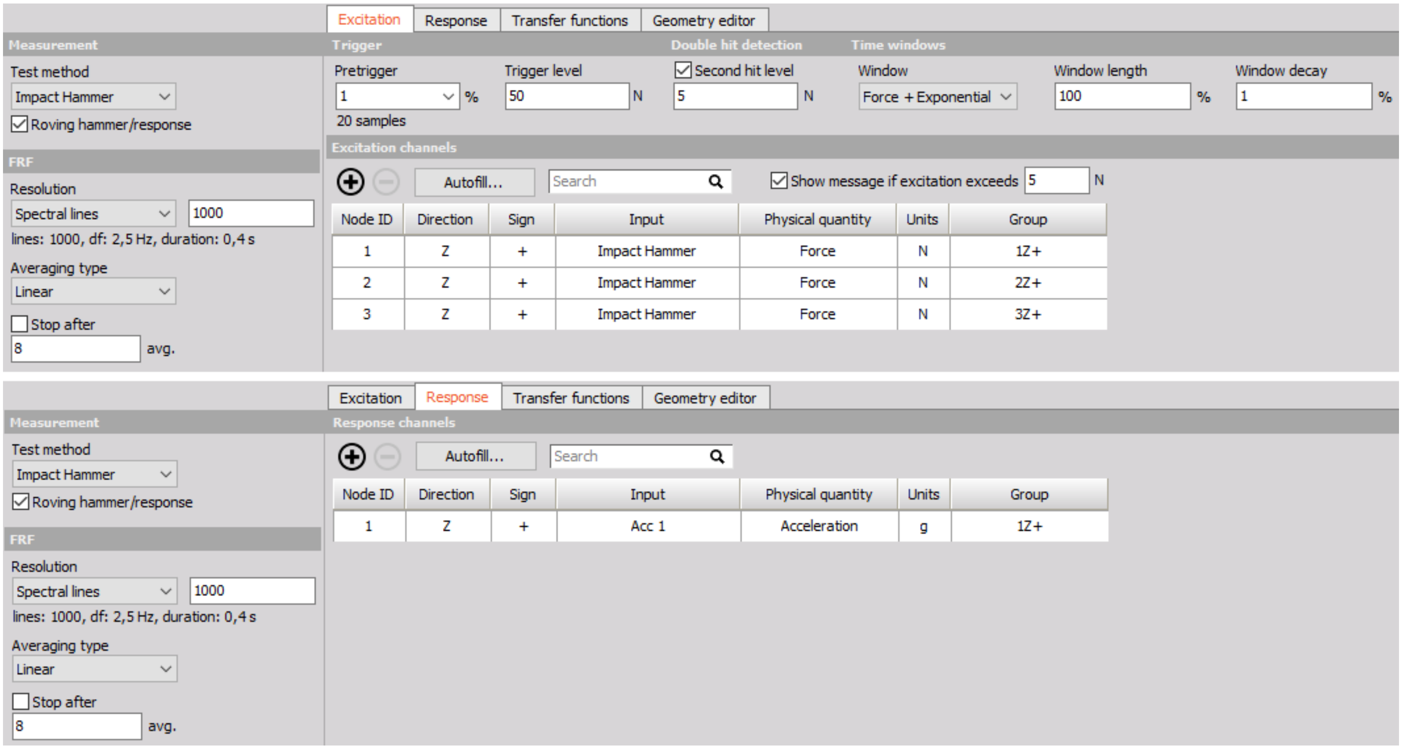
The assumption is that the selected reference DOF contains information about all the modes. This is possible if the reference DOF location can be chosen such that none of the modes are in a nodal position. In practice, this means that all the modes should be sufficiently 'present' in the measured data.

5.1.1 Single reference roving hammer test

For a Roving Hammer Test, this means that only one response DOF is needed, i.e., only one accelerometer position. For such a roving hammer test the accelerometer response DOF will be used as the reference DOF, while the hammer will rove between the DOFs. This is an example of what is called a Single-Input Single-Output (SISO) test configuration.



Impact hammer test configuration: Single output reference Response and single roving input Excitation

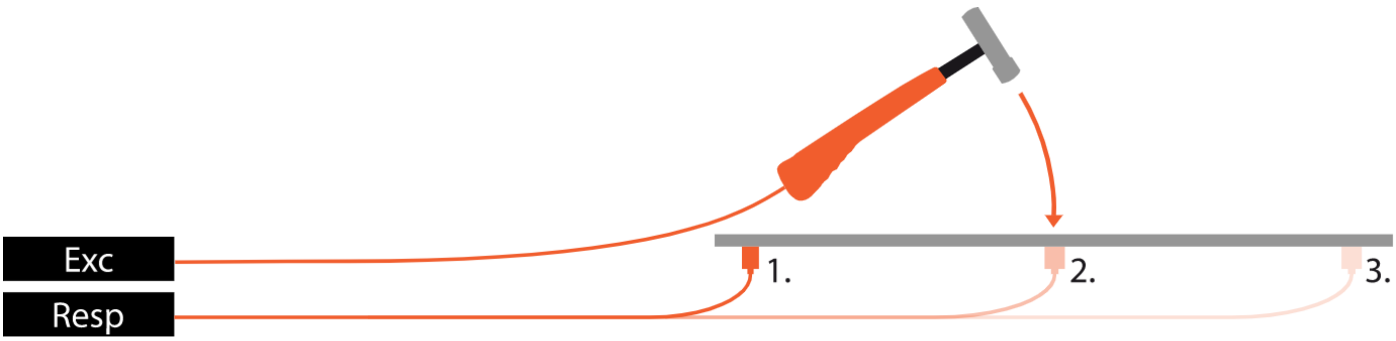


Module setup for a roving SISO test configuration with a single output reference Response and single, but roving, input Excitation used at 3 Node IDs.

5.1.2 Single reference roving accelerometer(s) test

Another type of roving test can also be selected, where it is the modal exciter (e.g. hammer or shaker) which are used as the reference DOF, while one or a group of accelerometers will rove until all DOFs have been measured. This is also referred to as a Roving Response Test.

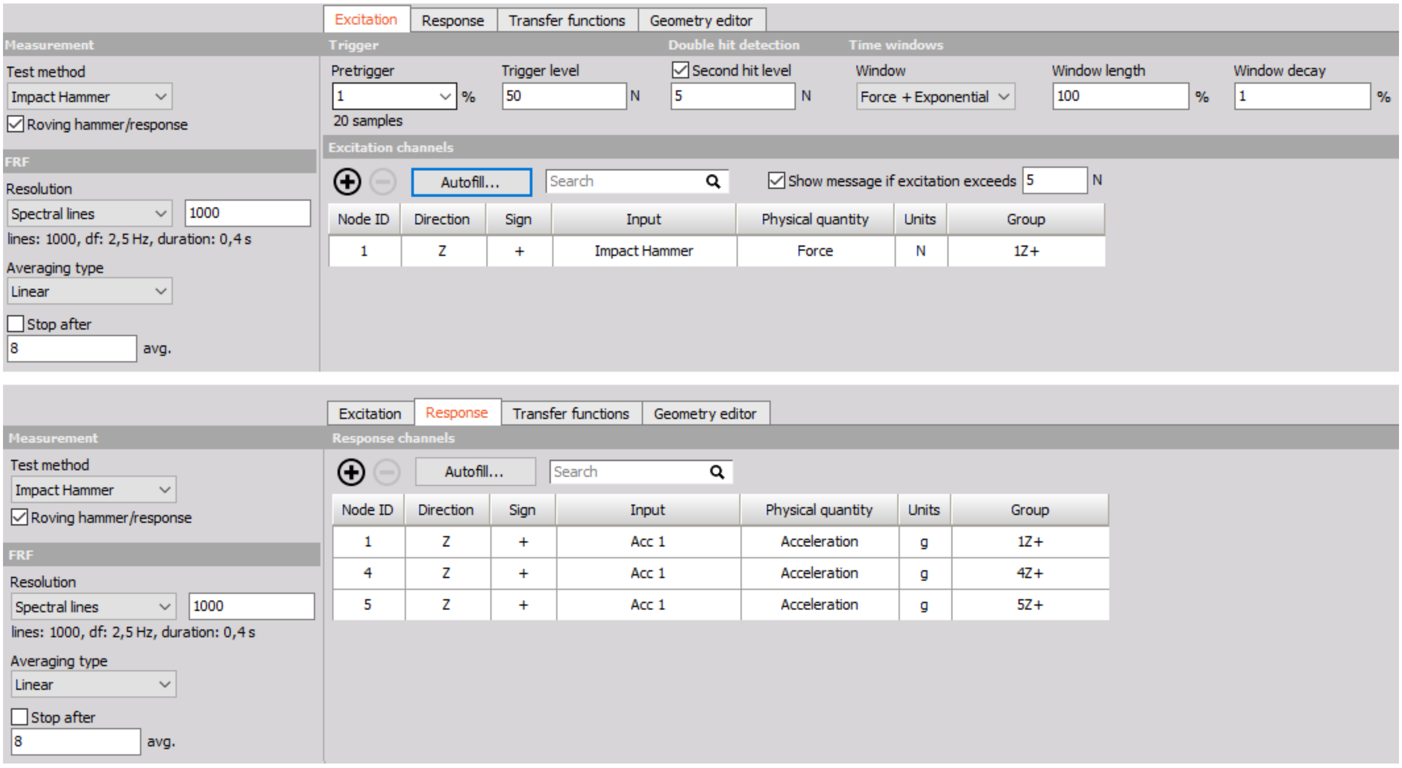
If multiple accelerometers are used it will be referred to as a Single-Input Multiple-Output (SIMO) test configuration.



Impact hammer test configuration: Single roving output Response and single input reference Excitation.

The disadvantage of this configuration is that the mass of the accelerometer affects the structure differently at every point, and therefore influences the measurement (this effect is called Mass Loading).

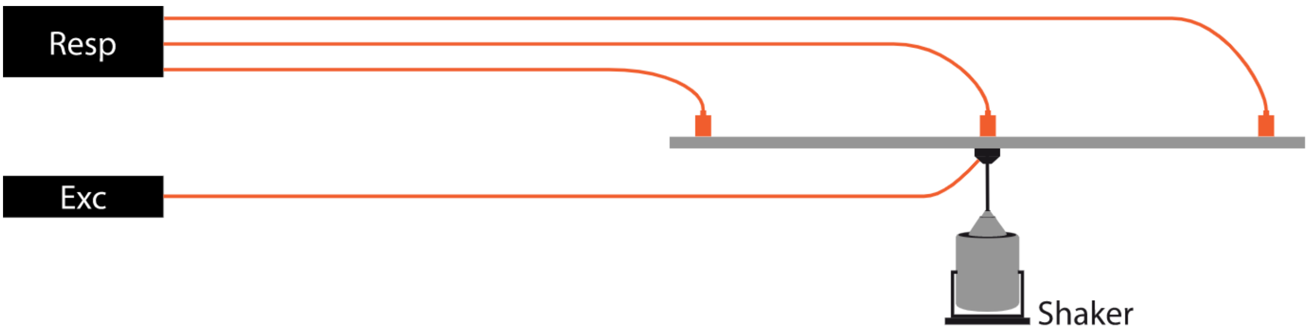
Also between each roving measurement, the sensor has to be moved and mounted again, which is more time-consuming than a roving hammer test.



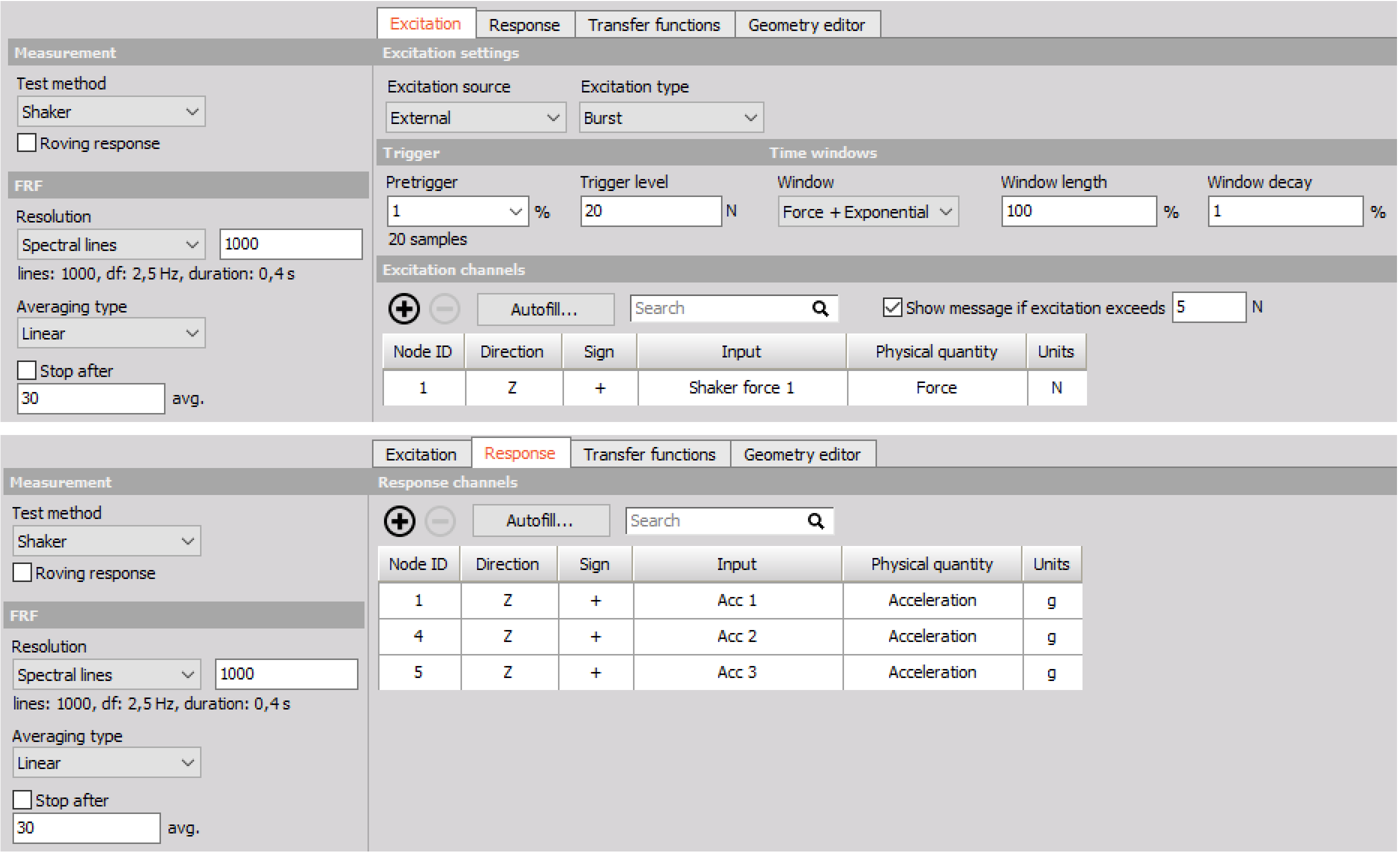
Module setup for a roving SISO test configuration, with a single roving output Response, used at 3 Node IDs, and single input reference Excitation.

5.1.3 Single reference shaker test

For a single reference modal test (where it is sufficient to extract the modal model using only one reference DOF), one modal shaker can also be used.
A modal shaker is often chosen for modal tests requiring a more accurate modal model determination. When using a modal shaker, the reference DOF is very often chosen to be the shaker excitation location, since force excitations at that location should excite most modes possible, and since it normally is more time-consuming to rove the shaker than roving a group of accelerometers.



Shaker test configuration: Multiple output Responses and a single input reference Excitation.



Module setup for a SIMO shaker test configuration, with multiple output Responses and single input reference shaker Excitation.

5.2 Multi-reference modal test

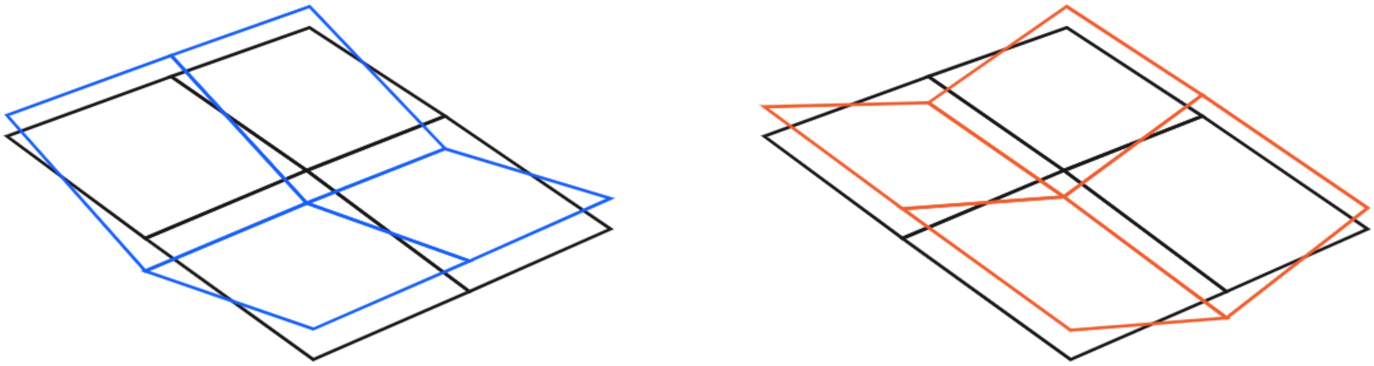
Some test cases require measurements with more than one reference DOF. This is the situation when it is not possible to find a proper reference DOF where all the modes are sufficiently 'present' in the measured data.

The structure could, for example, exhibit different modes with predominant modal deflections at different parts of the structure. Such modes are often referred to as local modes.

An example of this is complex structures composed of several different parts with different structural properties.

Multi-reference testing is also required in cases where the test object has more modes with the same resonance frequency. This is often referred to as 'repeated roots' and closely coupled modes.

An example of repeated roots is when having certain symmetrical structures. In such cases e.g. two bending modes perpendicular to each other could be closely coupled regarding their resonance frequency.

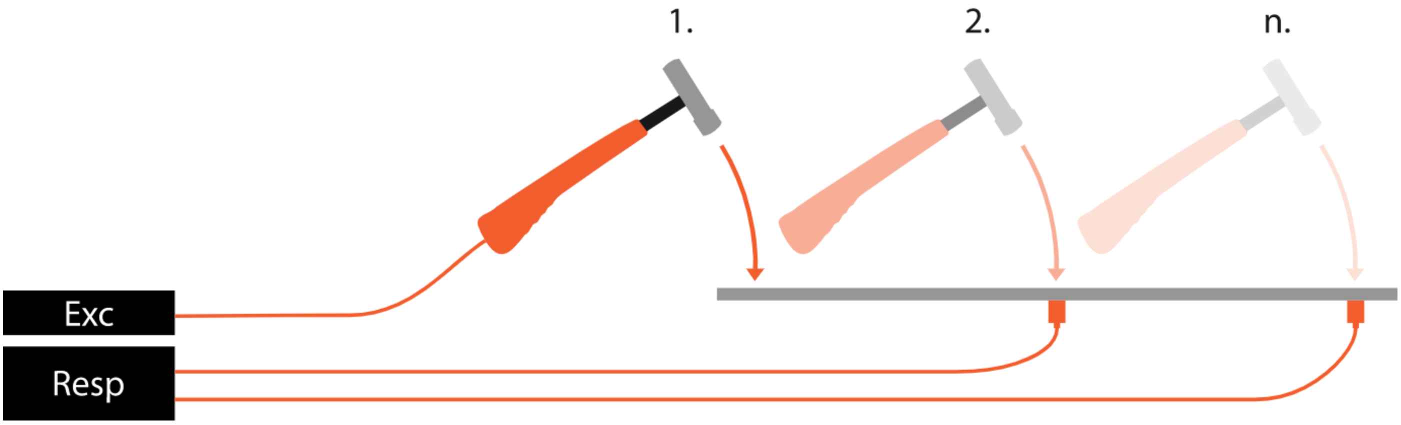


Sketch example of two different structural modes that appear at the same frequency. Such repeated roots would need more than one reference to be able to distinguish between what information belongs to which of the two modes.

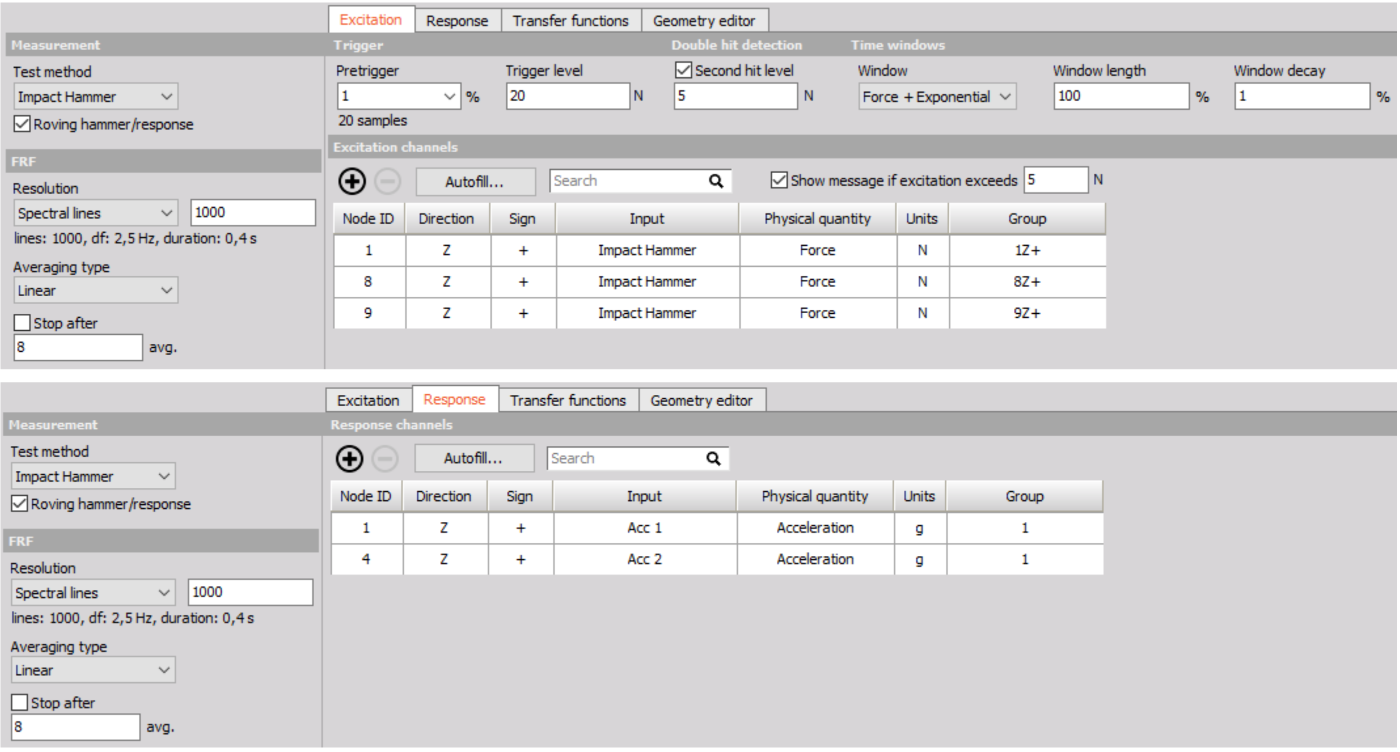
The number of reference DOFs measured must be (at least) equal to the number of modes at the same frequency.

5.2.1 Multi-reference roving hammer test

Regarding hammer testing, to include multiple reference DOFs in a modal test, this can be achieved by using multiple response sensors as reference DOFs.



Impact hammer test configuration: Multiple output reference Responses and single roving input Excitation.



Module setup for a SIMO roving Impact hammer test configuration, with multiple reference output Responses and single roving input hammer Excitation.

5.2.2 Multi-reference shaker test

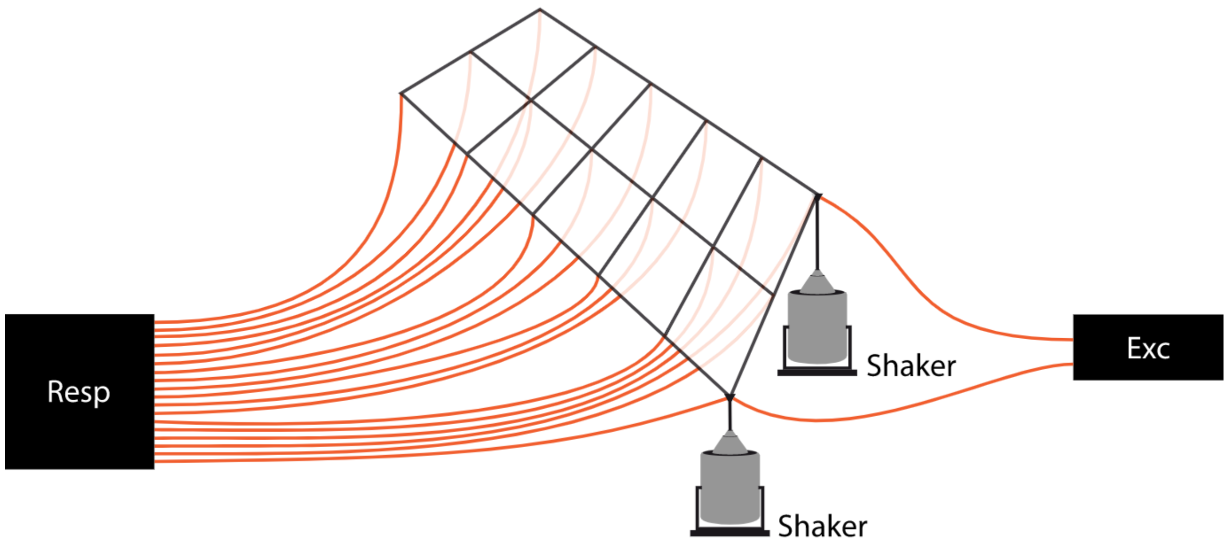
Multi-shaker tests are normally performed with more accelerometer sensors - hereby having a Multiple-Input Multiple-Output (MIMO) configuration.

The main advantage of using multiple shakers is that the input-force energy is distributed over more locations on the structure. This provides a more uniform vibration response over the structure, especially in cases of large and complex structures and structures with heavy damping.

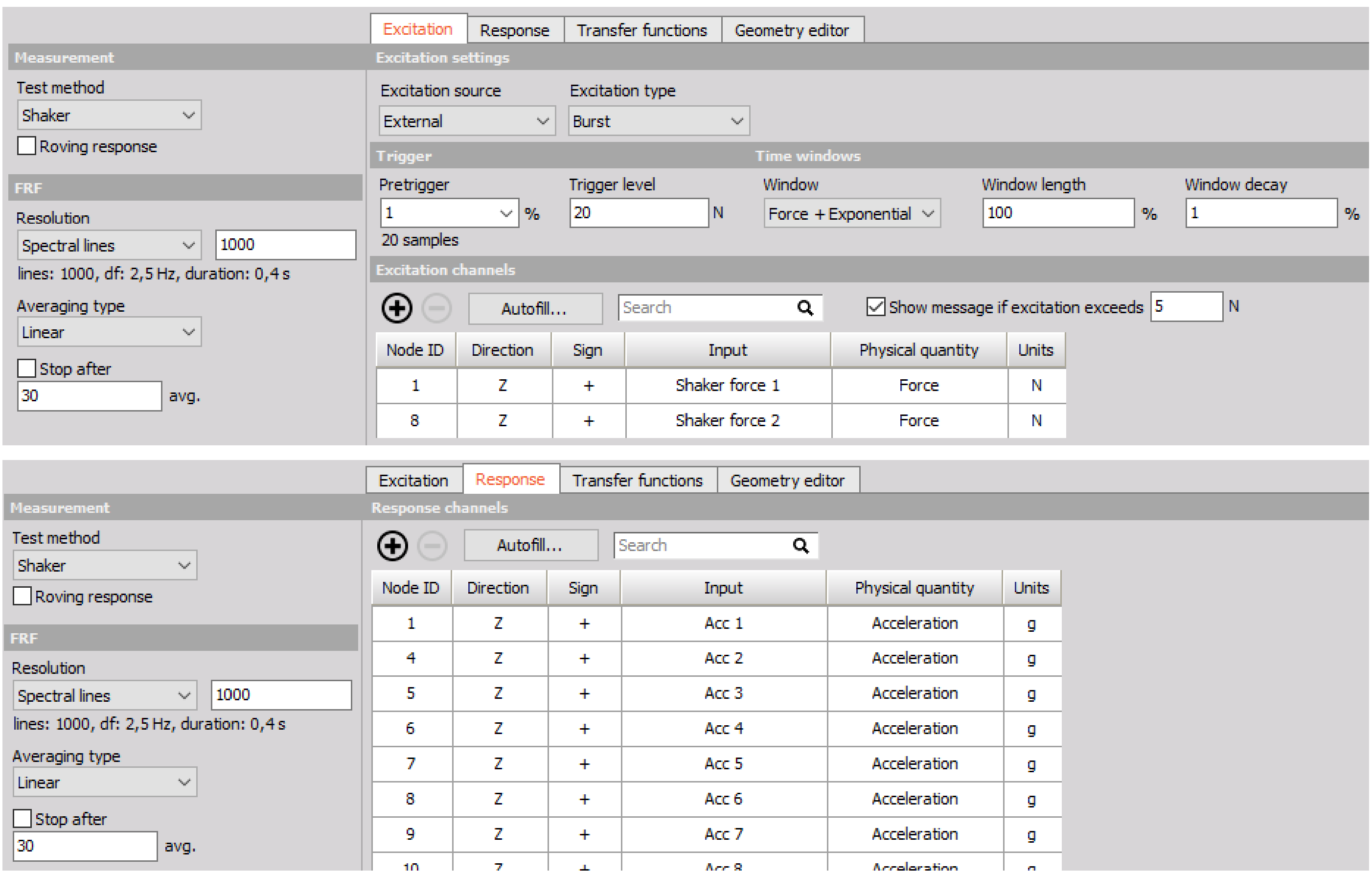
To get sufficient vibration energy into these types of structures, the input excitation level is often chosen too high when only a single shaker is used. This can cause non-linear effects and give bad estimations of the modal model. Excitation in more locations often also provides a better representation of the excitation forces that the structure experiences during real-life operation.

Using multiple shakers instead of roving a single shaker also has the advantage of providing more consistent data and reduced measurement time. Consistent data is crucial for the modal analysis performed on multi-reference modal test data.

When using multiple modal shakers, the excitation sensors are used as reference DOFs.



Shaker test configuration: Multiple output Responses and multiple input reference shaker Excitations.

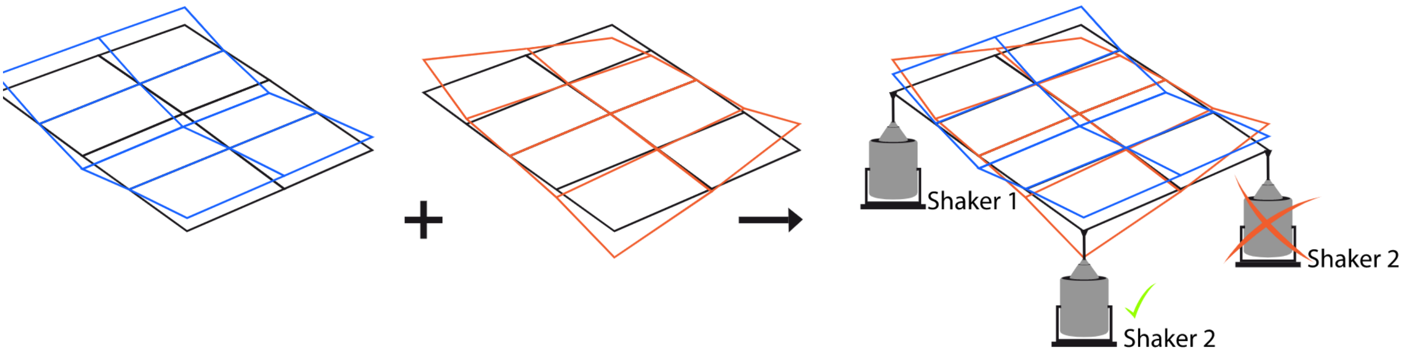


Module setup for a MIMO shaker test configuration, with multiple output Responses and multiple input reference shaker Excitations.

5.2 Distinguishable modes at the reference DOFs

In multi-reference configurations, the mode shapes that are to be extracted have to 'look differently' at the reference DOFs. That is to say, the mode shapes for these modes must be linear independent at the reference DOFs. This is achieved by selecting proper DOFs as reference DOFs.

As an example, a plate might have two closely coupled modes (resonance around the same frequency), where the deflection is similar for both modes at some DOFs. Let's say two reference DOFs are chosen to be at such two similarly deflecting DOFs - then the measured reference DOF data does not include information that can separate such modes.



Sketch example for a test with good and bad reference DOF locations. If Shaker 2 is located on the diagonal to Shaker 1 then the two shown closely coupled modes will deflect in a similar fashion for those reference DOFs. This is not the case if Shaker 2 is located at one of the other corners.

Sketch of first bending mode (left), first torsional mode (middle), and both modes together with a good and a bad position for two reference DOFs (right). If the modes have repeated roots, then the reference DOFs must be selected such that the modes reveal their differences.

5.3 Multi-reference excitation types

In multi-reference shaker tests, uncorrelated random excitation signal types are normally used. The random excitation types in DewesoftX can be continuous random or burst random.

Sinusoidal excitation signals can also be used in DewesoftX to perform Swept Sine Testing.
With Swept Sine Testing all applied energy can be focused on exciting one specific frequency at the time - hereby a significant amount of the input energy can be reduced (or focused at one frequency), compared to random excitation signals, where the energy is distributed over the full frequency span - covering all modes simultaneously.
Also, with swept sine testing it is possible to set the phase pattern between multiple analog output sine signals.

5.4 ODS (operational deflection shapes)

ODS Testing can be a valuable tool for analyzing and determining modifications for dominating structural vibrations on operating structures, where normal EMA is difficult to perform.

Examples of operational test conditions can be e.g. continuous signals from a running engine, or transient signals from earthquakes, explosions, drop-tests, and much more.

ODS testing determines the structural deflection shapes of an operating DUT by measuring amplitude and phase information of the DOFs.

ODS Testing does not use input excitation signals, but only output response signals. For Spectral ODS, one or more of the response DOFs are selected as the reference DOF(s) to extract the phase information. Note that the selected reference(s) need to cover energy from all frequencies/orders of interest.

For Time ODS no reference response channels have to be selected, since the used phase relations between the channels are included in the time signals.

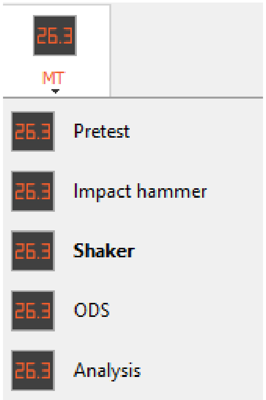
The results from ODS testing are animated deflection shapes on the Geometry indicating amplitude and phase relations.

6. Modal Test Measurement and visualization

6.1 Auto-generated displays

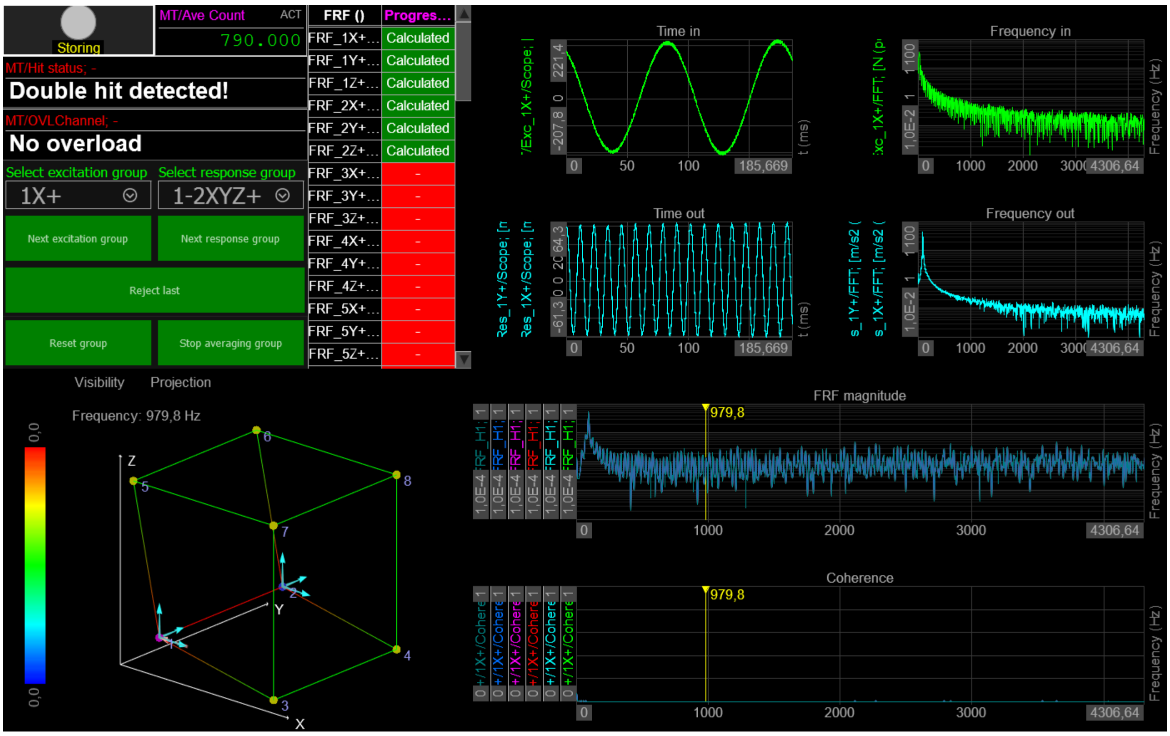
For an easier start, DEWESoft offers auto-generated displays, which already come with the most often used instruments and an arrangement that makes sense for the according type of application.

With the Modal test module added, usually when switching to measure mode, there should already appear a display group, called “MT”.



Pre-defined display templates for Modal test measurements.

If that is not the case, please go to Settings → User interface and enable the “Auto generate displays” checkbox. Then add a new Modal test module and go to measure to see the MT display group.

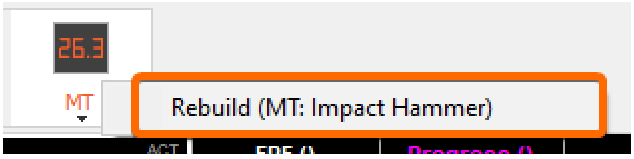


Example of a pre-defined modal test display template.

The excitation and response sections each consist of two 2D graph instruments (scope and FFT) showing array data of hammer and accelerometer signal. The Info channel will show the current point or events such as doublehit. The Control buttons are used for going from one point to the next, or cancelling and repeating a point if the result was not satisfying.. The Modal Geometry is already animated in the current point during measurement. Two further 2D graphs on the right side show transfer function and coherence of the point that is currently being measured.

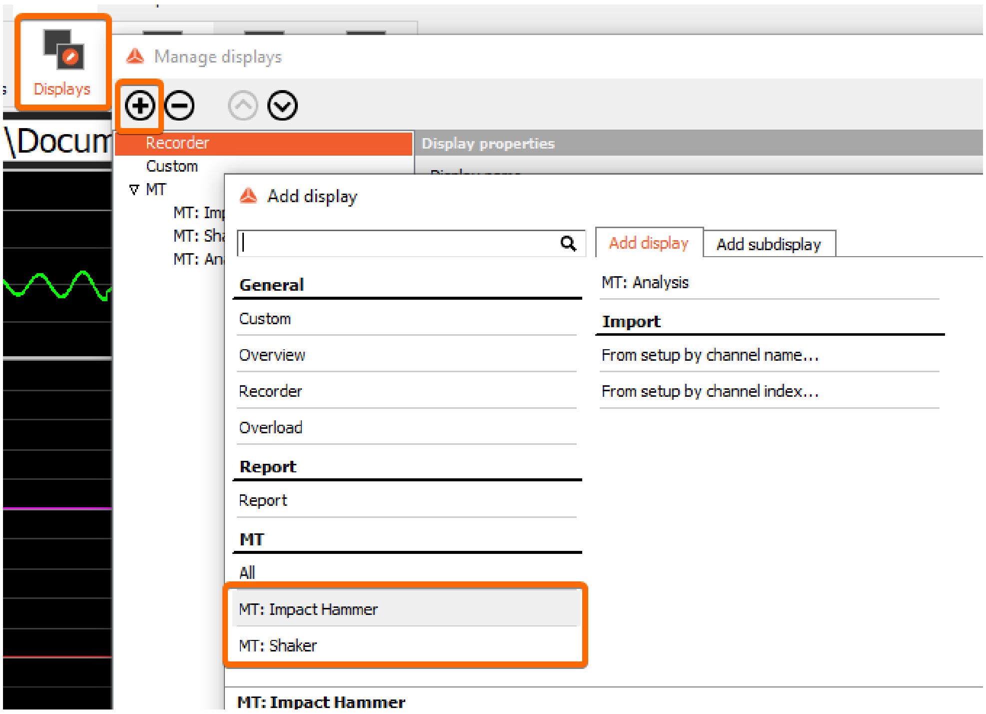
Important:

If the user makes changes in the modal test setup module the optimal display layout might change - For example, toggling Roving measurement on or off changes the need for some buttons in the display layouts.
The displays can be updated to match the newest changes in the MT setup module by right-mouse-clicking on the screen symbol in measure mode and then click "Rebuild".



Pre-defined display templates can be Rebuild if changes have been made to the modal setup.

To add a new display manually go to the Display section, select the plus button and add e.g. the whole MT display group (All) or a single MT display.



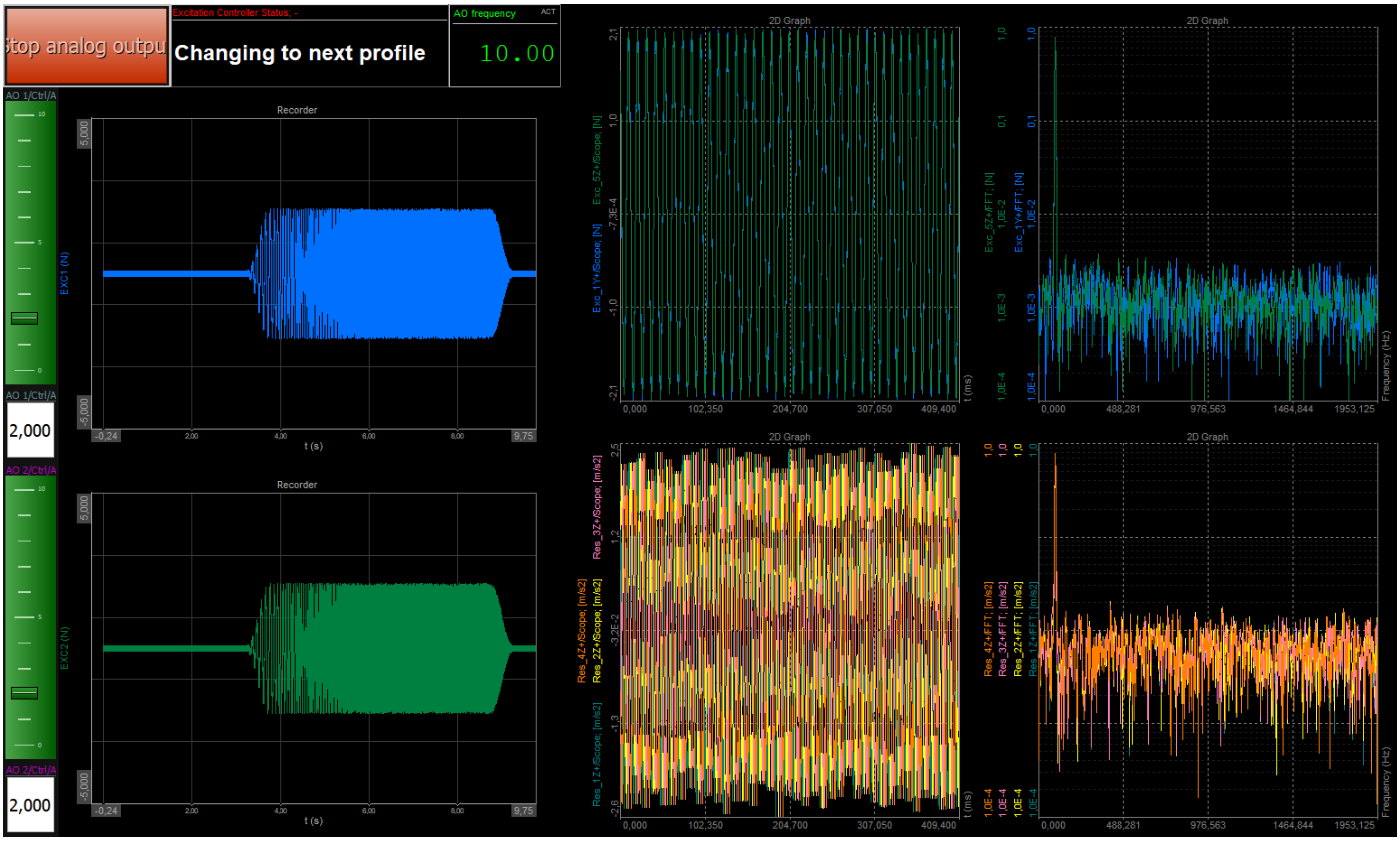
Click on Displays under Measure mode for manually adding new custom or pre-defined display templates.

6.1.1 Pre-test display

One of the auto-generated displays for the Modal test application is the Pretest display. The Pretest display can be of great help in the process of configuring an optimal test setup. Before starting the actual test measurements the pretest display can be used to monitor how the measurements will perform, and indicate if changes to the MT setup module should be done.

The default pretest display is applicable for all supported Modal Test methods (Impact hammer, Shaker and Spectral ODS).
If the Test method is changed later on, then the pretest display should be rebuilt to have the display template relating to the new test method.

In the picture below the pretest display is illustrated when doing a non-roving Shaker test with Dewesoft AO Sweep sine waveform.



Example of a pre-defined display template made to pre-test the configuration before starting the actual modal measurements.

6.1.2 Test method displays

A default display layout is included for all supported Modal test methods (Impact hammer, Shaker and Spectral ODS).

These displays are of great help to get a basic overview for how to perform Modal testing.
Depending on the test method and related display selected, the required user controls and relevant graph widgets are shown.
The user can modify the MT display templates as desired or build a totally new display by adding a new custom display. but having these default MT templates provides a great start for how widgets could be configured for MT.

Again, changing parameters in the MT setup module might affect the display for the used Test method, and the display should in such cases be rebuilt to include newest setup changes.

In the picture below the Shaker display is illustrated for a non-roving measurement using Dewesoft AO Sweep sine Waveform.

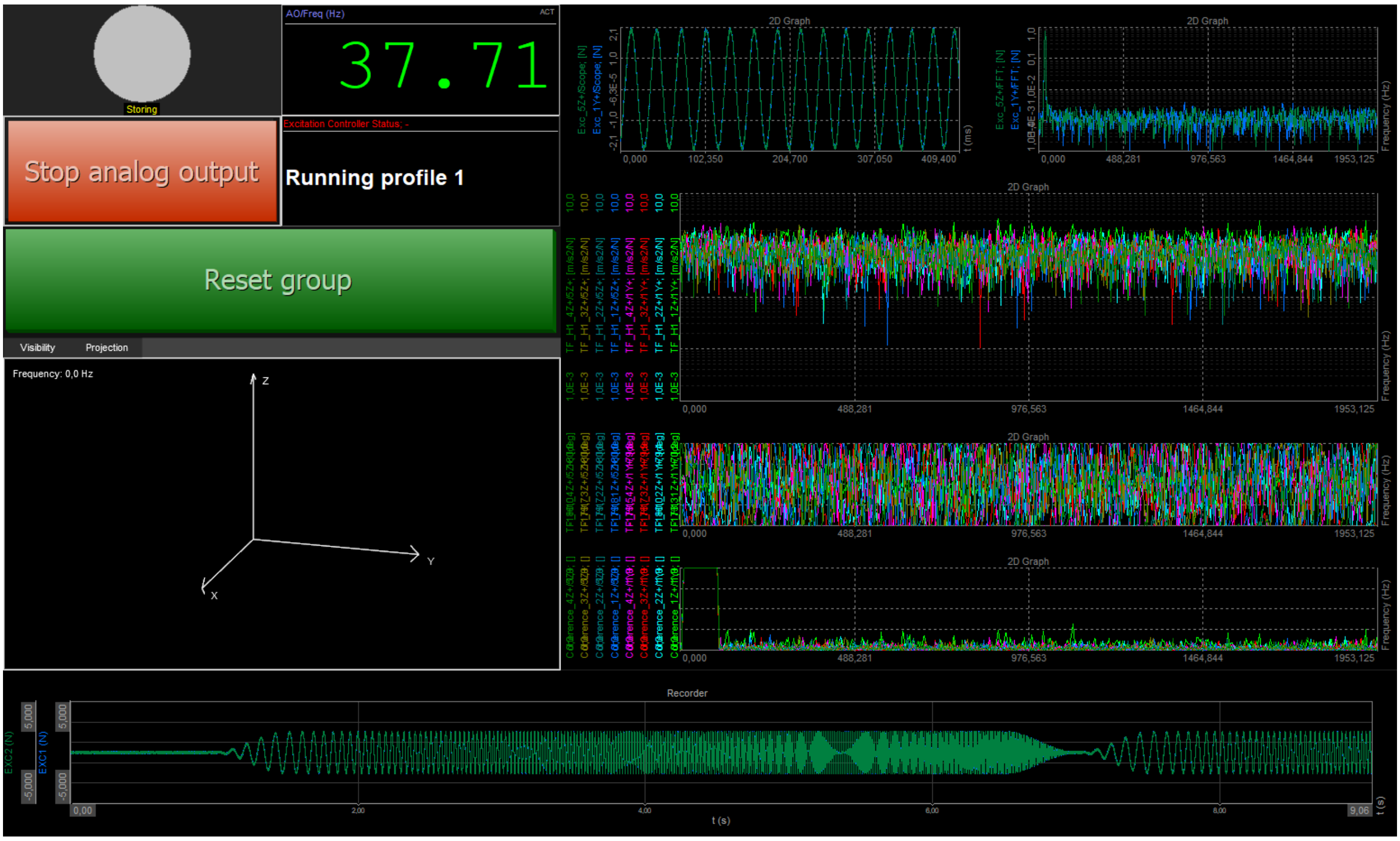


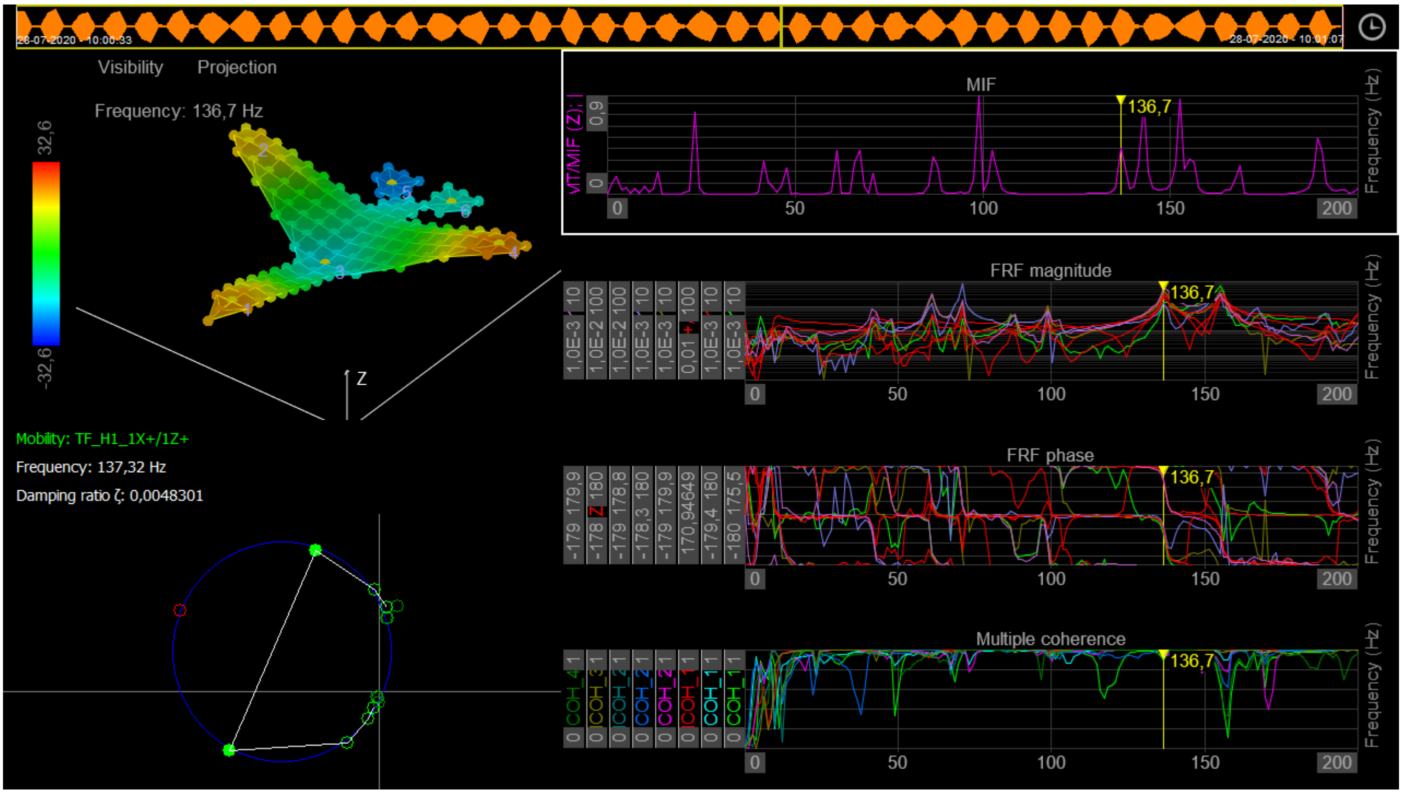
Illustration of a non-roving Shaker test measurement using Dewesoft AO with Sweep sine Waveform.

Note: The pre-defined display layout for Time ODS, (described in section 14.1.3) is generated when the stand-alone Time ODS module has been added to the setup.

6.1.3 MT Analysis display

Dewesoft Modal Test application also includes an Analysis display template, where measurement results can be investigated. MT analysis is mostly suitable when performing tests on simple structures, having few and well separated modes. For analysis of complex structures with many and closely spaced modes the Dewesoft Modal Analysis application should be used.

In the picture below the MT Analysis display is illustrated.



Example of how the pre-defined MT Analysis sub-display can look. This can be used for SDOF inspection using the Modal circle widget.

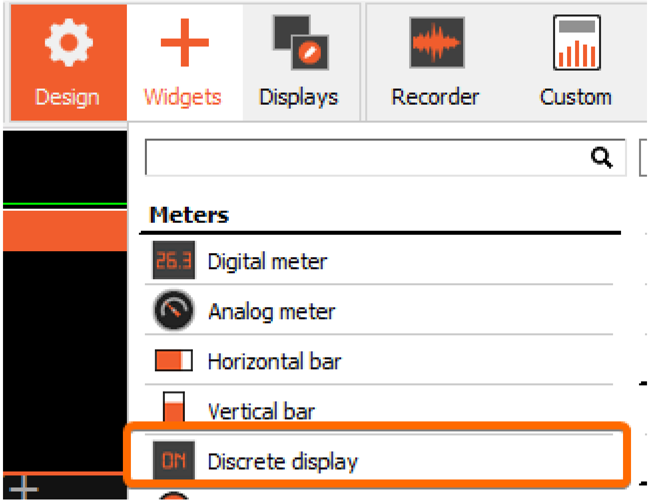
6.2 Modal test output results overview

- **FRF Transfer function** (FRF H1 or H2 estimators. Relative transmissibilities for ODS testing)
  - **Magnitude** - FRF magnitude relative to the reference
  - **Phase** - FRF phase relative to the reference
- **ODS FRF** (Absolute ODS)
  - **Magnitude** - Absolute response magnitude relating to measured response amplitudes.
  - **Phase** - phase relative to the reference
- **Ordinary coherence** - is a real value between zero and one. If the value is one then response power is caused totally by input power. A value less than one indicates that measured response power is greater than that from input power, e.g. due to noise.
- **Multiple coherence** - used in MIMO calculation. If the value is one then response power is caused totally by input power. A value less than one indicates that measured response power is greater than that from input power, e.g. due to noise.
- **PSD** - Power Spectral Density is the measure of signal's power content over frequency.
- **Ordinary mode indicator function** - Mode Indicator Function (MIF) is a function ranging from zero to one and shows where resonances are.
- **Intermediate Fourier transform** - FFTs of excitation and response channels during the measurement.

6.3 Modal test common channels

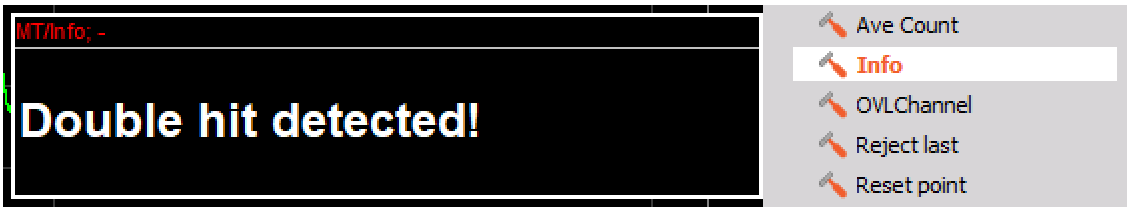
- **Info** - information about which point is currently measured or a information about double hit detection
- **Ave Count** - a number of collected averages.
- **Reject last** - this is a channel which can be used with visual control to reject the last sample (overload of channels, double hit...).
- **Next point** - this is a channel which can be used with visual control to go to the next point when grouping is used.

There are additional info channels provided by the Modal test module, which give status information during the measurement. To display them, please add a Discrete display in design mode:



Adding a Discrete display widget to a Measure display.

The channels “Info” and “OVLChannel” can be assigned to it. OVLChannel will only be displayed if the according option has been enabled first.



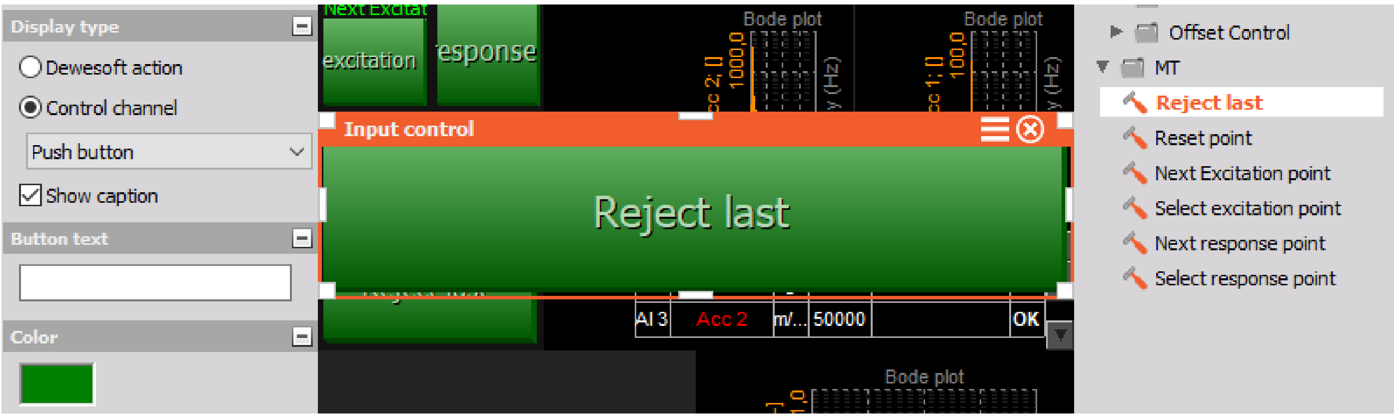
Info channel from Modal test added to a Discrete display widget.

Overload detection channel from Modal test added to a Discrete display widget.

6.3.1 Modal test control channels

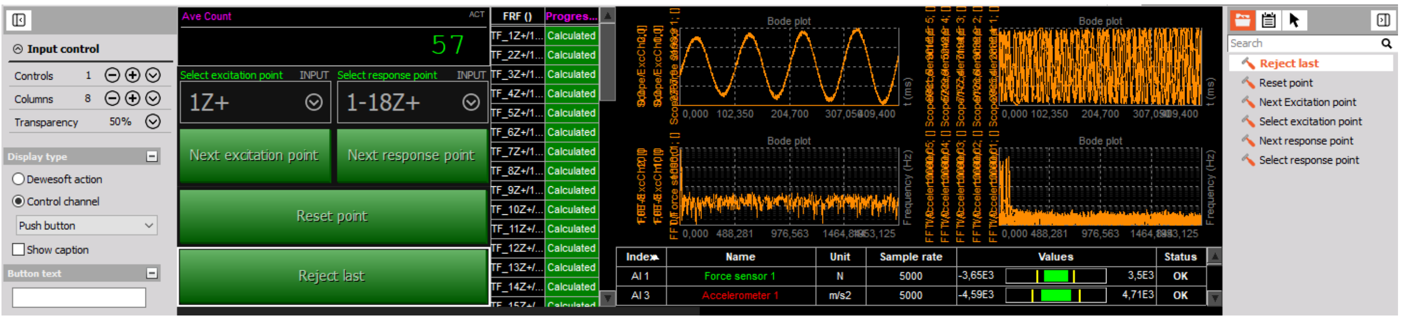
- During triggered measurement, after one point is finished, you can continue by pressing the **“Next point”** button (Next excitation point or Next response point).
- If you are unsatisfied with the last hit, you can cancel it by using **“Reject last”**.
- If all hits for the whole point are incorrect, e.g. if you hit on a point with a wrong number, with **“Reset point”** you can delete all the hits done for the current point at once.

All the actions are done using “control channels'' in DEWESoft. These can be modified during measurement. To change it manually, you need to pick the “Input control” widget from the instrument toolbar. Set it to the Control Channel and Push button. Channels “Reject last”, “Next point” and “Reset point” can now be assigned from the channel list on the right.



Control channels for Modal test are used with Input control display widgets.

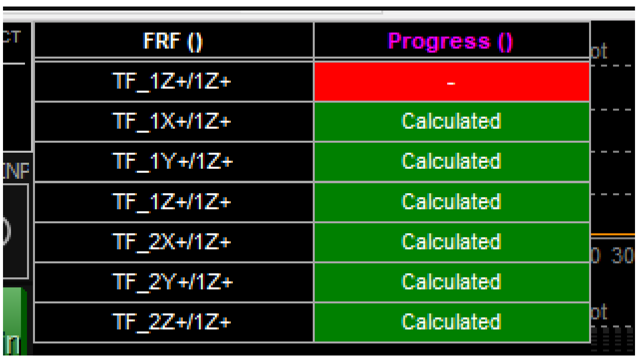
When you exit the design mode, you are able to press the buttons.



Multiple Input control widgets set to operate as Push buttons. Each button is linked to a control channel from Modal test.

6.4 Progress table

In the Progress table all the transfer functions that were defined in the Modal test module are listed. When the transfer functions of each group are calculated you will see a green indicator (Calculated). Until the point or group is measured, it will remain red.



FRF ()	Progress ()
TF_1Z+/1Z+	-
TF_1X+/1Z+	Calculated
TF_1Y+/1Z+	Calculated
TF_1Z+/1Z+	Calculated
TF_2X+/1Z+	Calculated
TF_2Y+/1Z+	Calculated
TF_2Z+/1Z+	Calculated

A 2D/3D table widget is used to show which of the FRFs are ready, and hereby to show the progress of the Modal test.

6.5 Autofill setup

NOTE: If you wish to use Autofill (for response channels) for triaxial sensors you must connect the response channels (Triaxial accelerometers) in a manner of: 1st sensor X, Y, Z, 2nd sensor X, Y, Z, and so on.

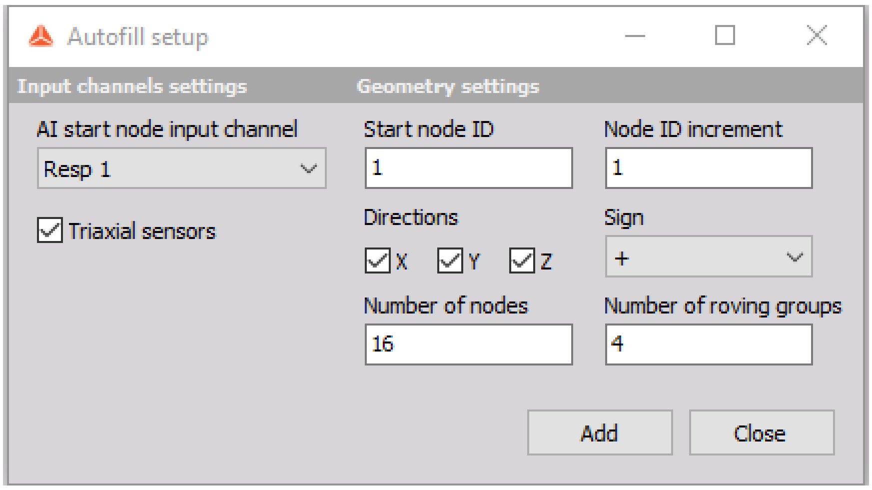
Select the channel that will measure the first node of the structure under the AI **start node input channel**.

Option Triaxial sensors is available only for response channels, and not for excitation channels.

Geometry settings:

- Start node ID - Define the starting point node of the structure
- Node ID increment - Set the increment by which the nodes will advance
- Direction(s) - Select the direction(s) of the measurement (if Triaxial response you can select multiple X, Y and Z)
- Sign - Define the orientation of the sensors
- Number of nodes - Define the number of nodes being measured at the same time (in same group)
- Number of roving groups - Define how many times the group of measured nodes is roving

For example, in the picture below 16 triaxial response sensors are roving 4 times, giving 3 (directions) * 16 (nodes) * 4 (groups) = 192 response channels.

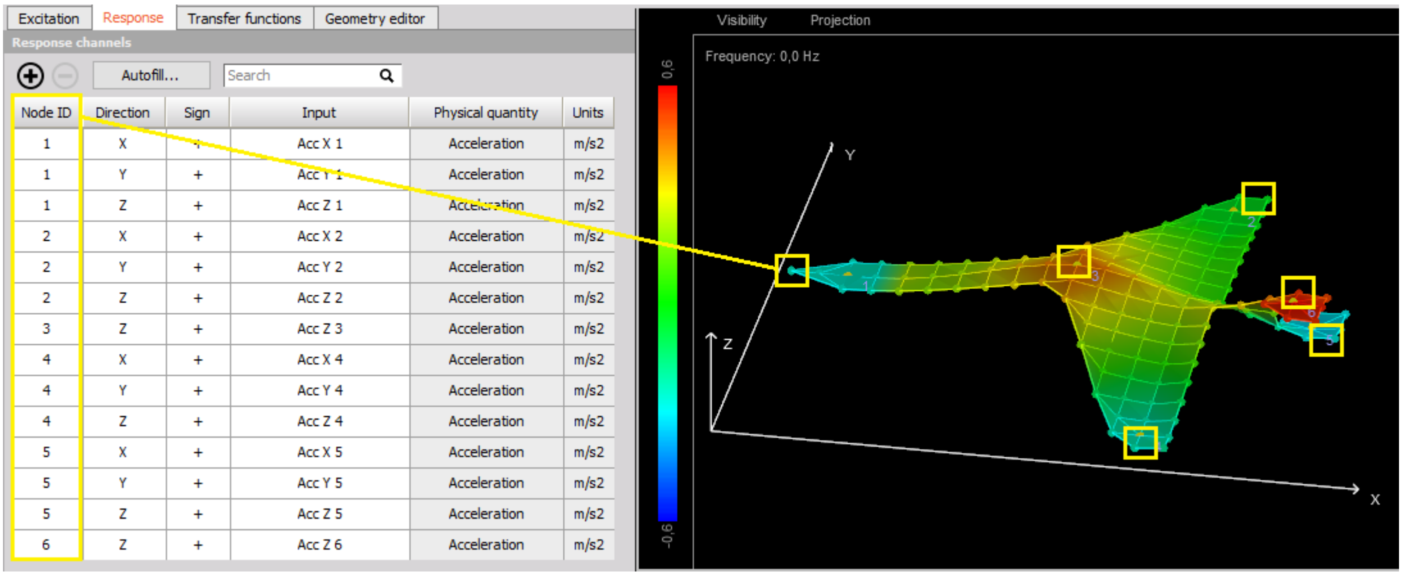


*16 nodes are measured at the same time. This is repeated at 4 different groups of sensor locations. Each sensor contains 3 channels (X, Y, Z). This will Autofill all XYZ channels in all nodes in all groups giving 3 * 16 * 4 = 192 response DOFs.*

6.6 Modal geometry widget

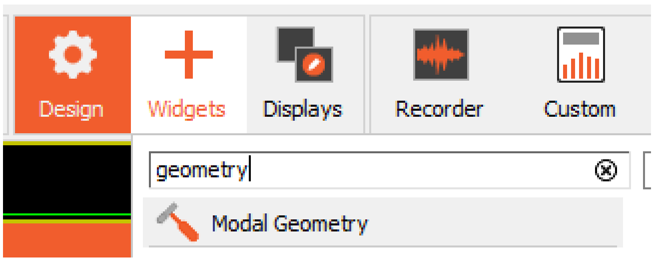
In DEWESoft you can quickly draw structures, as well as import already existing ones. A cartesian and cylindrical coordinate system is supported, which is great for drawing circular objects.

Please note that the maximum number of points in the geometry is limited to 10000 nodes.



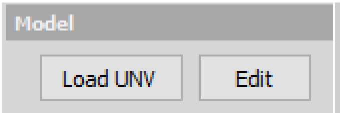
The Node IDs of the defined Excitation and Response DOFs are linked to the Node IDs of the geometry. The Geometry editor can be accessed both from the dedicated Modal test setup tab and under Measure mode as a display widget.

The geometry can be managed in the Modal Test setup under the Geometry editor tab, or in Design mode we can add the “Modal Geometry” widget.



Manually adding a Modal geometry display widget to a display in Measure mode.

Then you can either load a UNV (universal file format) geometry file, or create your own in the Editor.

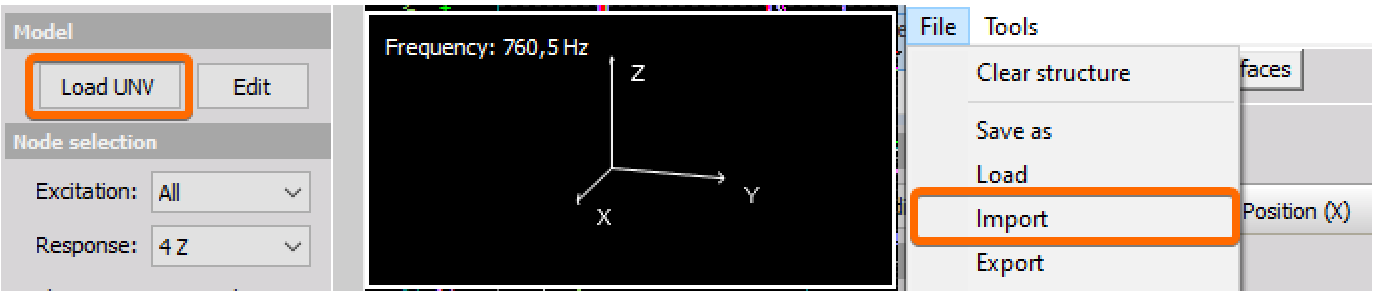


Modal geometry widget properties support both loading of pre-defined structures and creation of new structures.

6.6.1 Importing a structure

There are two ways of importing a UNV / UFF (universal file format) geometry of other software (e.g. MEScope or Femap) into DEWESoft. Of course you can also import a geometry drawn in the DEWESoft Modal geometry editor before.

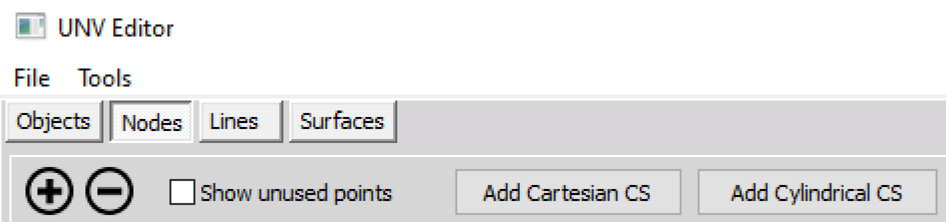
From the properties of the FRF geometry instrument on the left select "Load UNV", or go to the Editor and Import the UNV file there.



To use pre-defined structural geometries, either Load them directly from the widget properties or use Import under the Geometry editor.

6.6.2 Drawing a structure

To draw a structure enter the UNV editor. In the UNV editor we can add Objects, Nodes, Lines and Surfaces. All the points and objects can be defined in the Cartesian coordinate system or Cylindrical coordinate system.



With the UNV or Geometry editor pre-defined object types, individual nodes, connecting lines, and surfaces can be defined to build a specific structural representation of the test specimen.

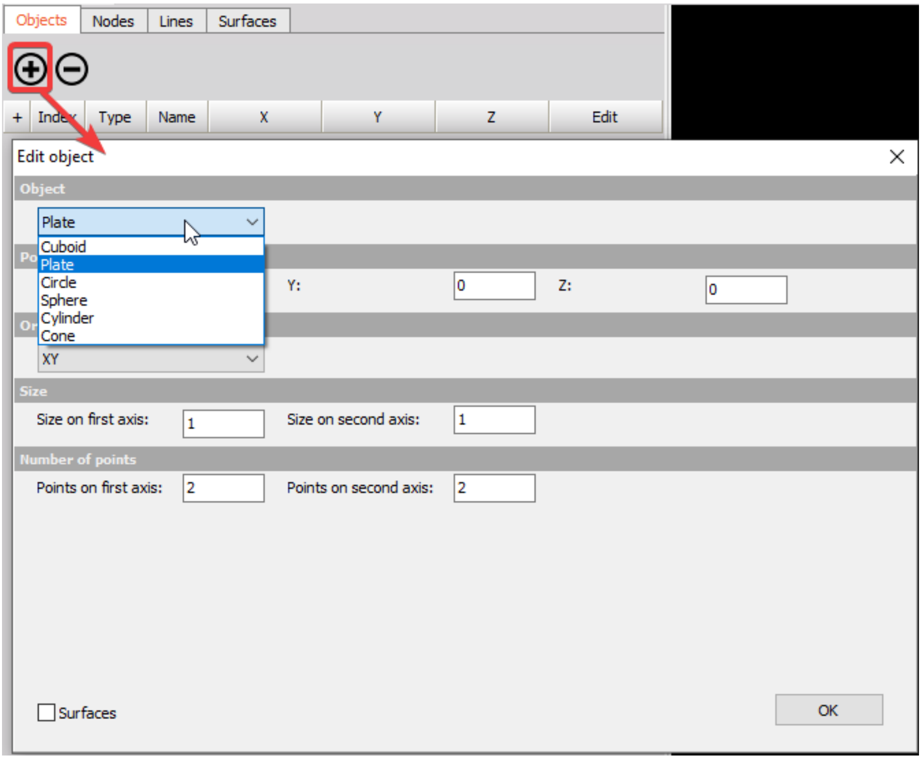
Objects

The structure can be assembled from pre-defined objects. The object that are available in Geometry are:

- Cuboid
- Plate
- Circle
- Sphere
- Cylinder
- Cone

For each object you can define the position (X, Y and Z coordinate), size (of axis) and number of points in each axis.

If the user selects option Surfaces, the surfaces will automatically be assigned to the structure.



Selecting between object types to add. For each object the number of defined nodes and their position can be defined.

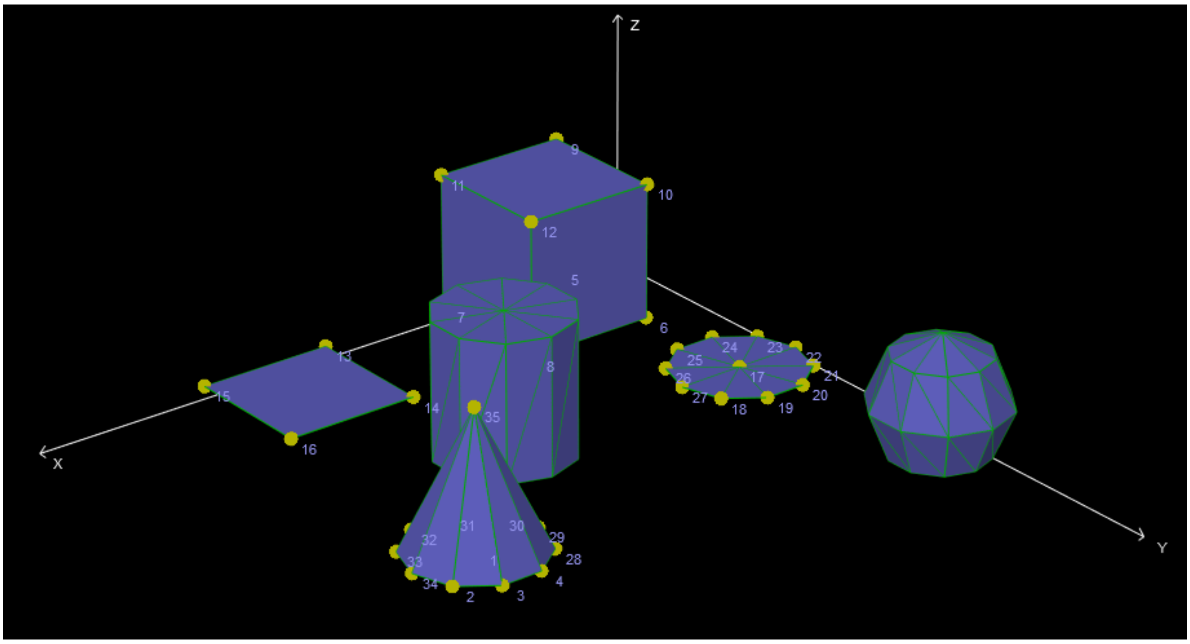


Illustration of multiple different object types added to the Geometry editor with surfaces included.

When you select an object and use the right mouse button you will also have following options:

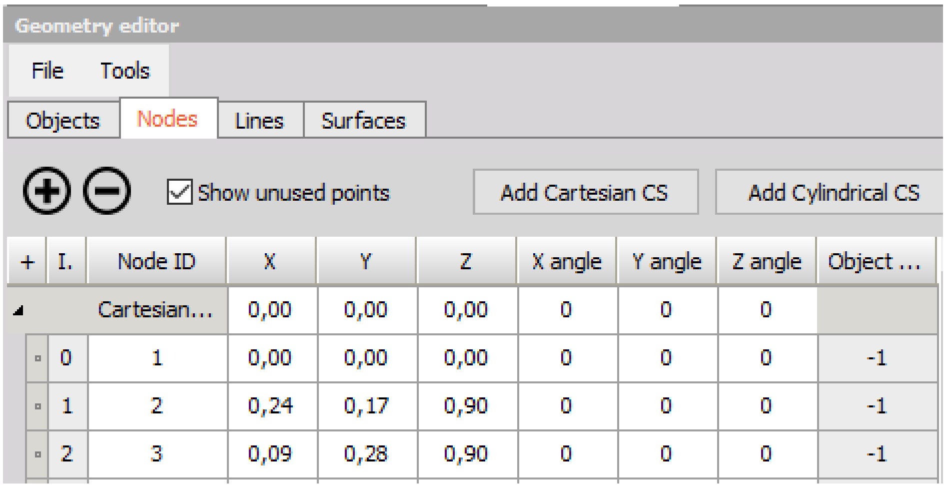
- Group - group selected nodes into an object
- Ungroup - ungroup selected object into nodes
- Duplicate - duplicate selected nodes/objects
- Delete - delete selected nodes/objects

Nodes

Under the Nodes tab you can link the channels, used in the setup, to the geometry. The setup channel Node ID numbers are linked to the geometry Node ID numbers.

Nodes are points where the sensor is positioned on an object. Nodes are defined with location (X, Y, Z) and rotation around axes (X angle, Y angle, Z angle). In order to create a new structure from nodes, we have to switch to the Nodes tab. Now we have to create a coordinate system in which we will define our nodes. This can either be Cartesian or Cylindrical.

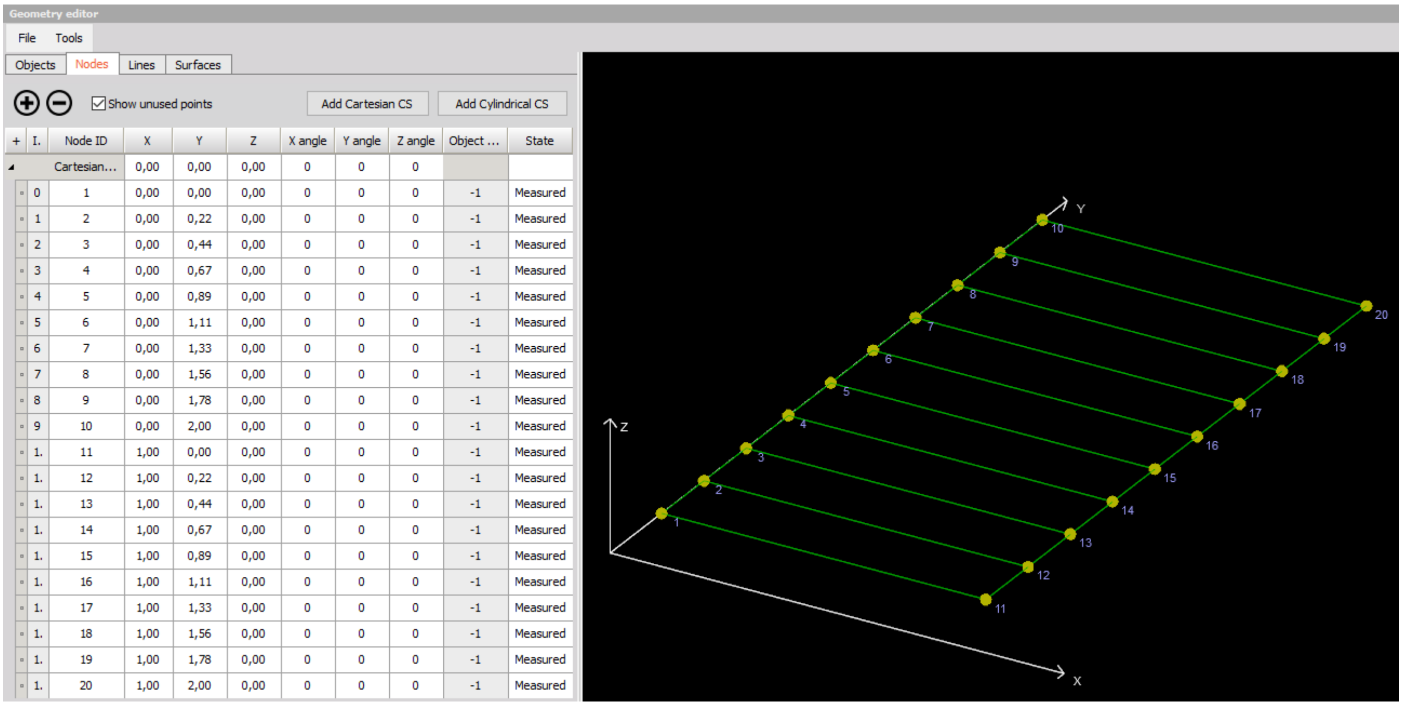
After the coordinate system is created, we can add nodes with the Plus button.



+	I.	Node ID	X	Y	Z	X angle	Y angle	Z angle	Object ...
◢		Cartesian...	0,00	0,00	0,00	0	0	0	
▫	0	1	0,00	0,00	0,00	0	0	0	-1
▫	1	2	0,24	0,17	0,90	0	0	0	-1
▫	2	3	0,09	0,28	0,90	0	0	0	-1

Under the nodes tab all individual nodes are listed with their Node IDs. For each node the position and rotation can be modified.

In the picture below, you can see the Cartesian coordinate system with 20 nodes.



+	I.	Node ID	X	Y	Z	X angle	Y angle	Z angle	Object ...	State
◢		Cartesian...	0,00	0,00	0,00	0	0	0		
▫	0	1	0,00	0,00	0,00	0	0	0	-1	Measured
▫	1	2	0,00	0,22	0,00	0	0	0	-1	Measured
▫	2	3	0,00	0,44	0,00	0	0	0	-1	Measured
▫	3	4	0,00	0,67	0,00	0	0	0	-1	Measured
▫	4	5	0,00	0,89	0,00	0	0	0	-1	Measured
▫	5	6	0,00	1,11	0,00	0	0	0	-1	Measured
▫	6	7	0,00	1,33	0,00	0	0	0	-1	Measured
▫	7	8	0,00	1,56	0,00	0	0	0	-1	Measured
▫	8	9	0,00	1,78	0,00	0	0	0	-1	Measured
▫	9	10	0,00	2,00	0,00	0	0	0	-1	Measured
▫	1.	11	1,00	0,00	0,00	0	0	0	-1	Measured
▫	1.	12	1,00	0,22	0,00	0	0	0	-1	Measured
▫	1.	13	1,00	0,44	0,00	0	0	0	-1	Measured
▫	1.	14	1,00	0,67	0,00	0	0	0	-1	Measured
▫	1.	15	1,00	0,89	0,00	0	0	0	-1	Measured
▫	1.	16	1,00	1,11	0,00	0	0	0	-1	Measured
▫	1.	17	1,00	1,33	0,00	0	0	0	-1	Measured
▫	1.	18	1,00	1,56	0,00	0	0	0	-1	Measured
▫	1.	19	1,00	1,78	0,00	0	0	0	-1	Measured
▫	1.	20	1,00	2,00	0,00	0	0	0	-1	Measured

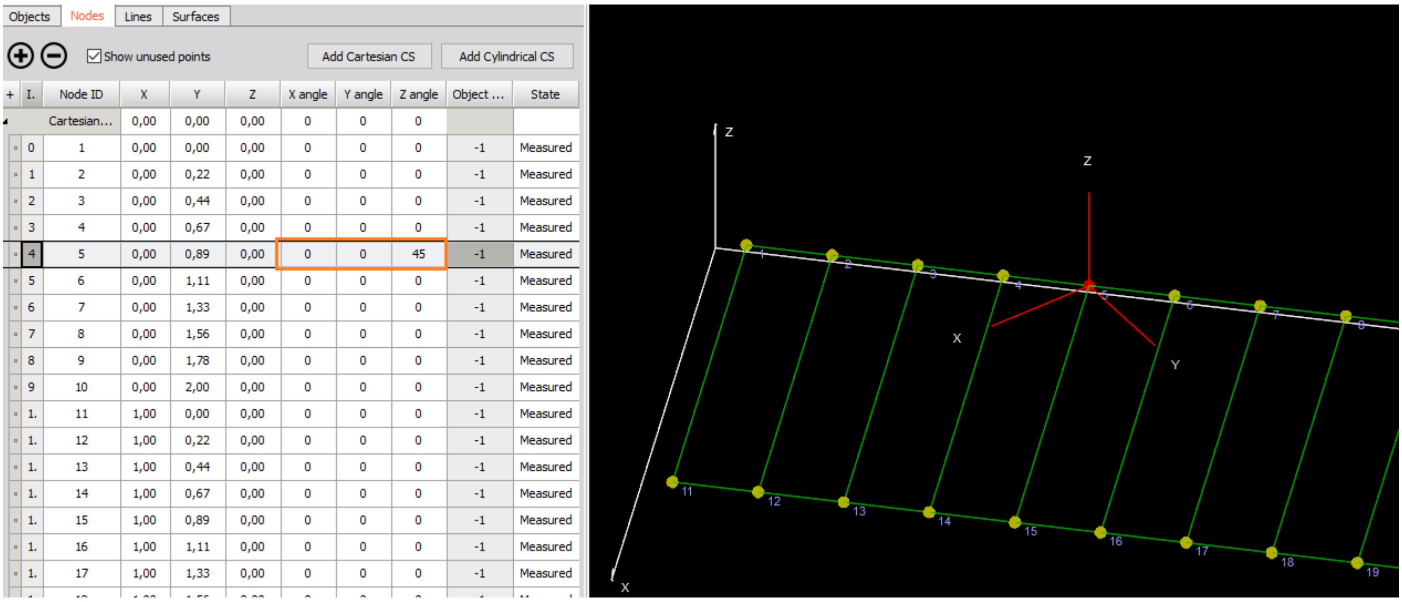
Example showing 20 nodes connected with lines.

After nodes are created we can change their rotation (according to how the sensor is rotated on the object) with all three axes.

Note that the physical sensor orientation and the related Geometry node point orientation must match, in order to animate correct deflection shapes.

If multiple nodes are rotated in a similar way, then add an additional coordinate system and define that CS to have such rotation. In that way all nodes belonging under that CS will have such rotations applied.

Nodes can be selected with selection in the node table or with the right mouse click on the structure preview window. When a node is selected, rotation is shown with a small coordinate system located directly on the node. In the picture below you can see selected and rotated nodes.



Each node can be rotated to match possible sensor rotations.

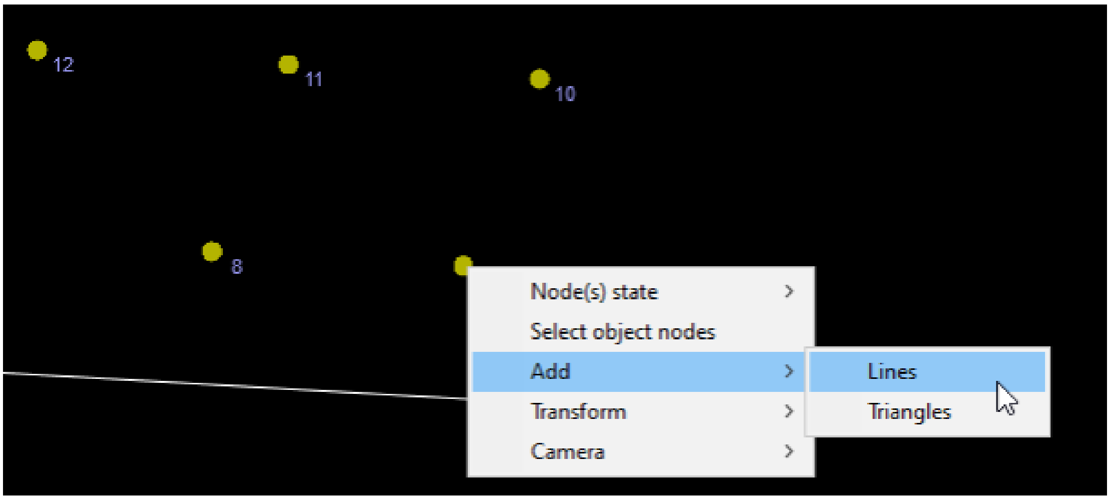
When a node is selected, we can remove it by pressing the Minus button on the nodes tab.

Nodes state can be:

- **Measured** - point in the structure that we measured. The color of the point is yellow.
- **Unmeasured** - point in the structure that was not measured. In order to animate unmeasured points, it must be connected with a line to a measured point.
- **Hidden** - hidden point in the structure

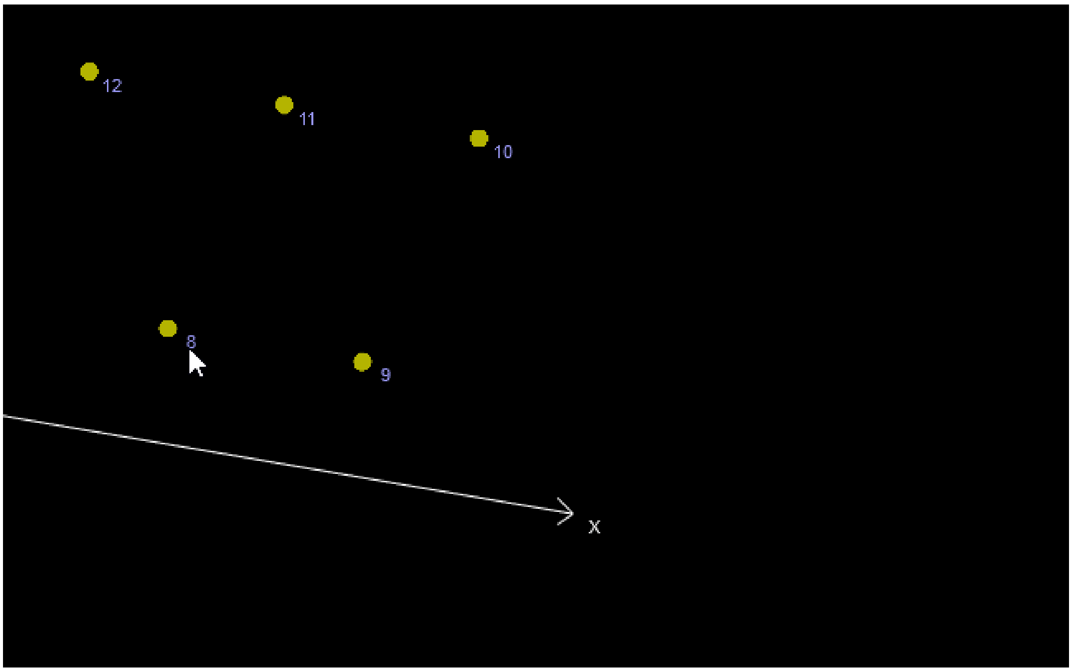
Lines

When nodes are defined we can go ahead and add lines to connect them.
Easiest way to create lines is to right click with the mouse on the node, select Add -> Lines.



Lines between nodes can be added directly by right clicking on a node in the animation window, and then select Add -> Lines.

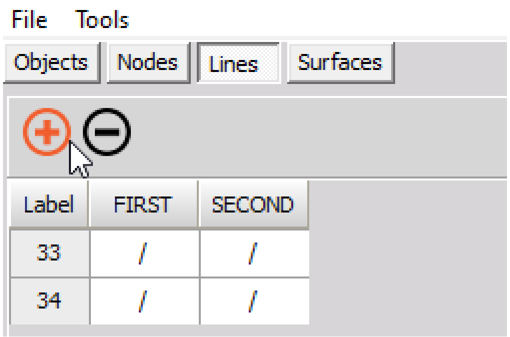
Left click on the first node and move to the second node. This will create a white line and when you hover to the node, the line will change to green color. Select the second node and the line will be added.



Animated example of the workflow for adding lines between multiple nodes.

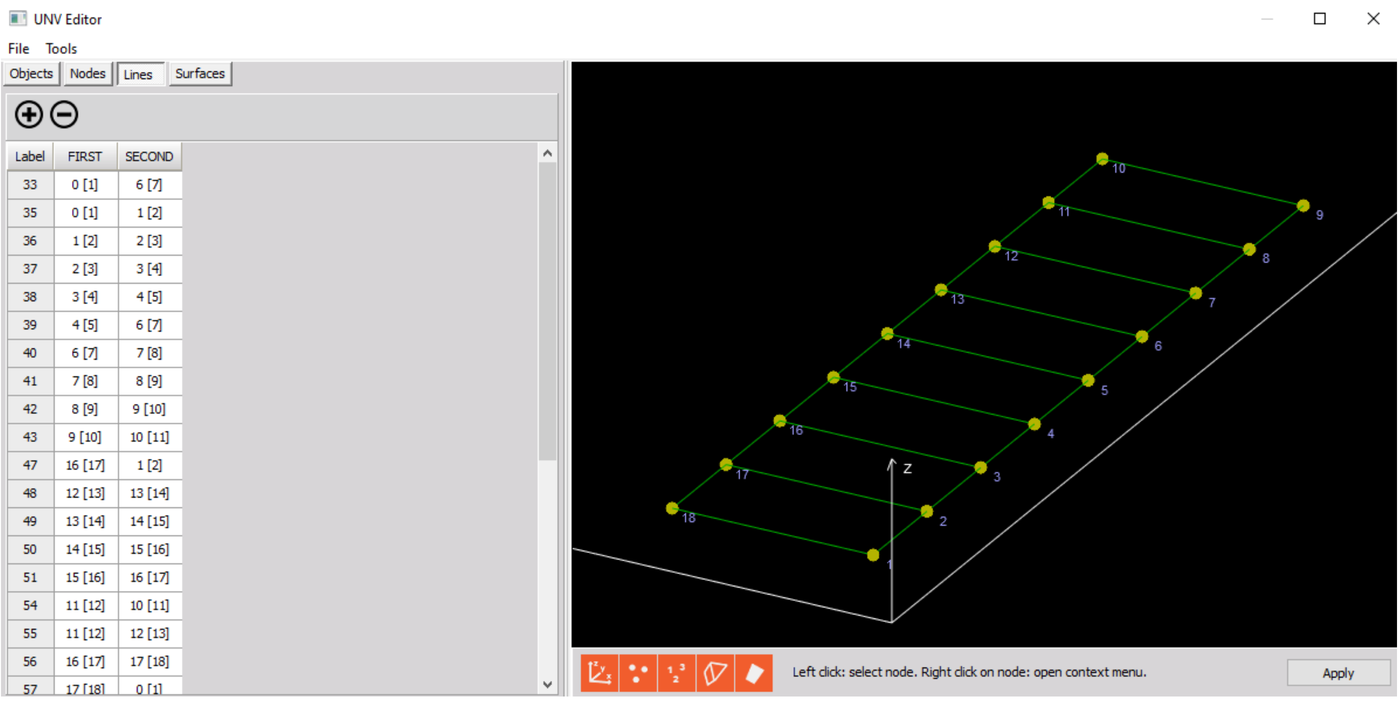
You can add multiple lines consecutively. Right mouse click will stop adding lines.

If we don't want to draw a connected line, we can also manually add lines by pressing on the Plus button in the Lines tab.



Lines can be defined between nodes one-by-one through the Lines tab in the Geometry editor. The columns called First and Second are the nodes which the lines will connect.

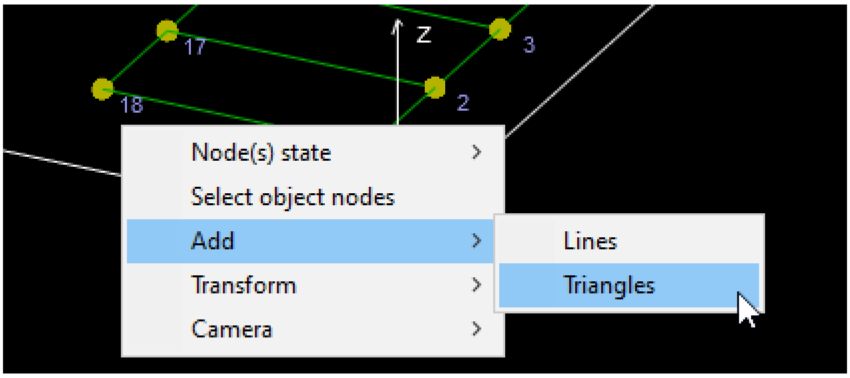
With that new line added to the Lines table, we have to select which nodes that should be connected – we can do that by selecting nodes in the table under the First and Second column.
In the picture below we can see objects with some trace lines added.



Example of lines added between nodes. The Lines table shows how the lines are defined.

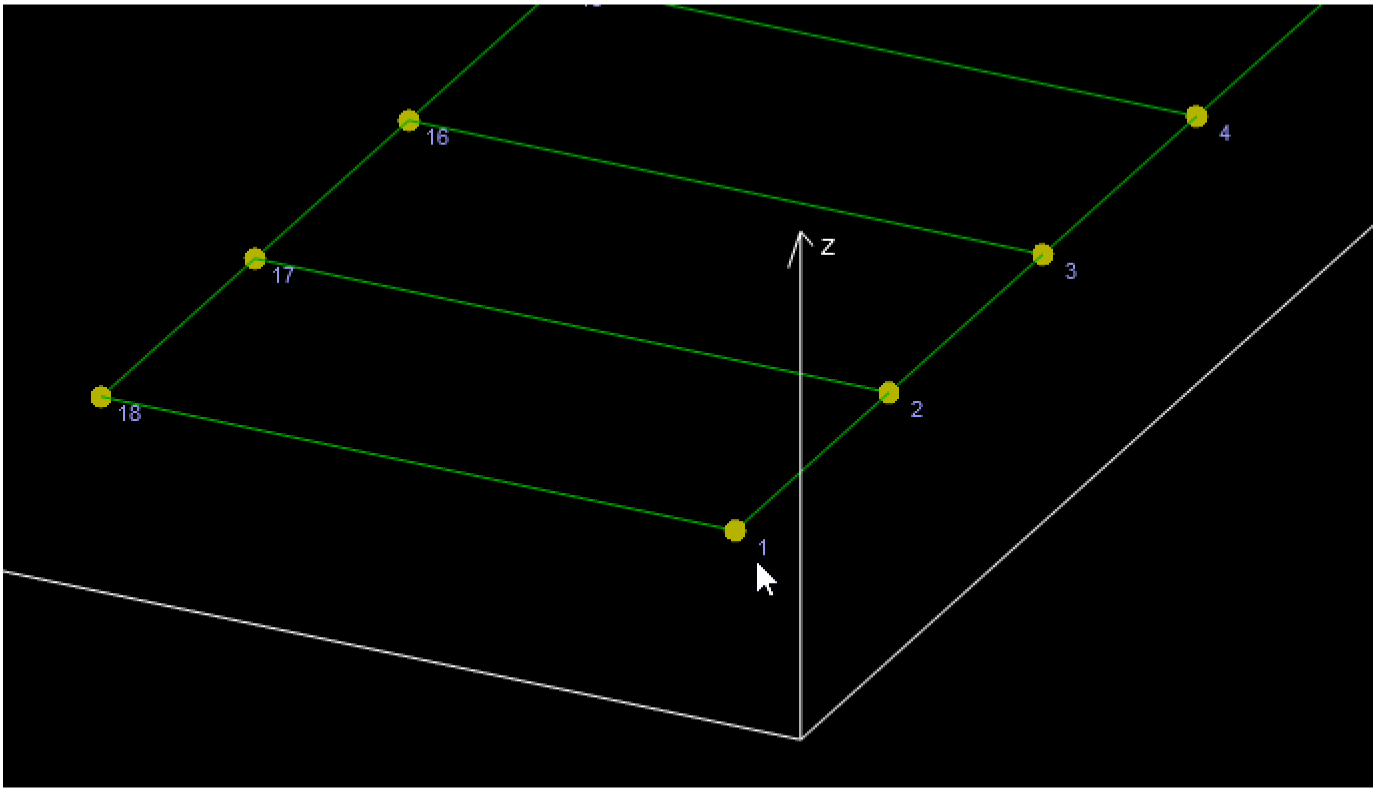
Surfaces

Surface can be defined with 3 nodes.
Triangle surfaces can be added with a right mouse click, Add -> Triangles.



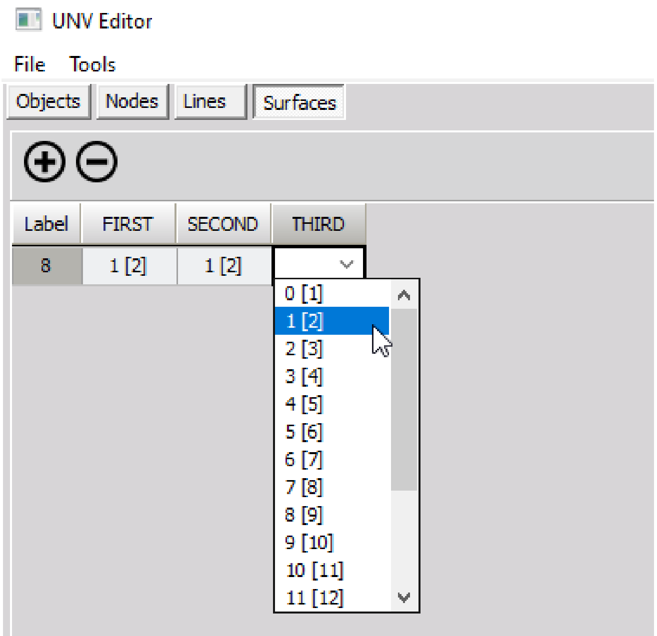
Surface triangles can be added directly in the animation display by right clicking on a node and selecting Add -> Triangles.

In order to add a triangle surface, 3 points must be selected as shown in the image below.



Animation showing how groups of three nodes are selected for each surface part.

Triangle surfaces can also be added by clicking the plus button and manually defining corners.



Triangle surface parts can also be added manually in the Surface tab. The columns in the Surface table are used to select the three related nodes for the surface part.

6.6.3 Additional options

- Clear structure - the whole structure will be cleared
- Save as - save the geometry as an XML file
- Load - load existing XML file into the editor
- Import - import UNV/UFF files
- Export - the structure can be exported to UNV/UFF file format
- Exit - option will close the UNV editor and discard all your changes.

Cartesian coordinates

Usually nodes are presented with a Cartesian coordinate system. This means you have X, Y, Z position and rotation around all three axes. Coordinate system can be used for grouping nodes, because you can later rotate or translate them with the Center point.

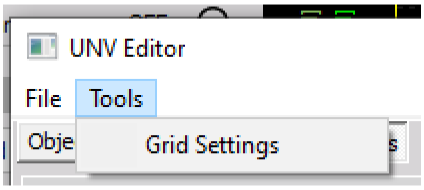
Cylindrical Coordinates

Cylindrical coordinate system is used for easier creation of round objects. Points are defined with radius, angle and z (height) around coordinate systems center point.

Cartesian and cylindrical CS can be combined in one geometry.

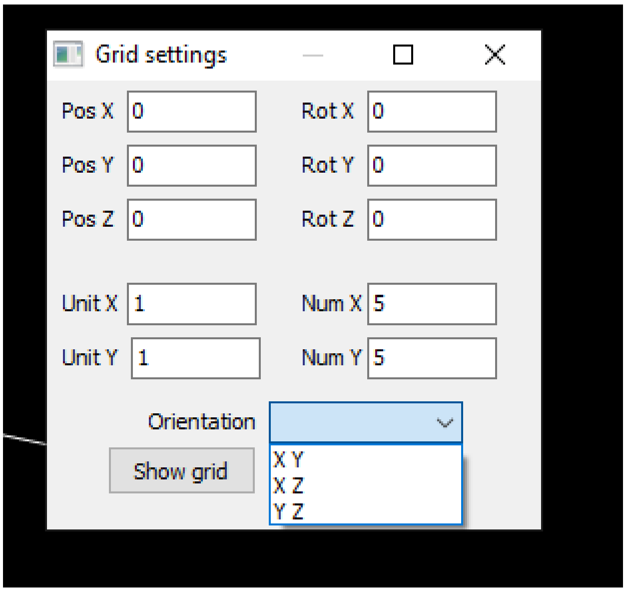
6.6.4 Grid settings

Under Tools -> Grid settings a grid can be added into the coordinate system.



Grid settings used for the Geometry animation.

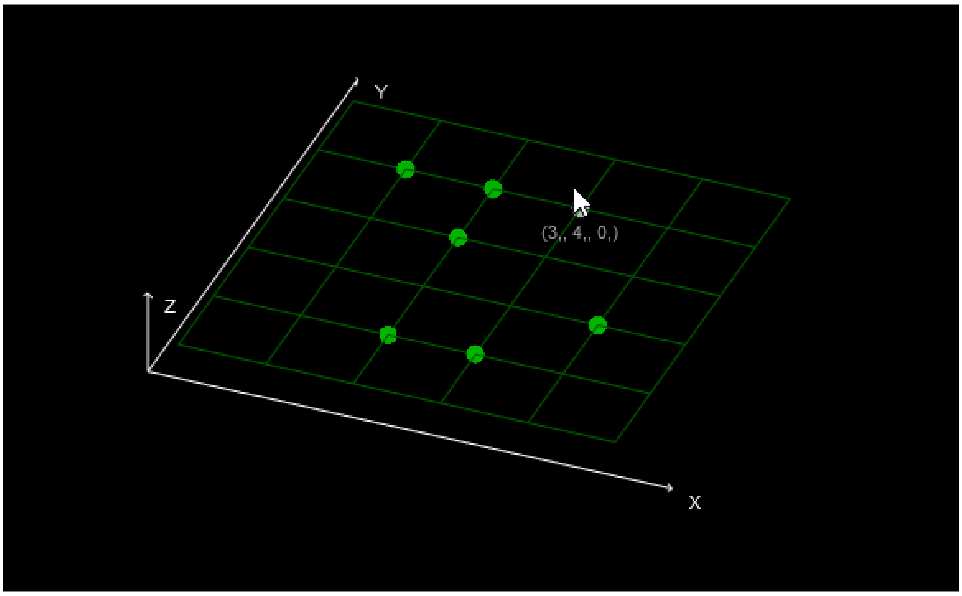
Users can define the position, rotation, orientation and size of the grid.



Supported Grid settings including grid position, orientation, and dimension sizes.

The grid is displayed in the coordinate system.

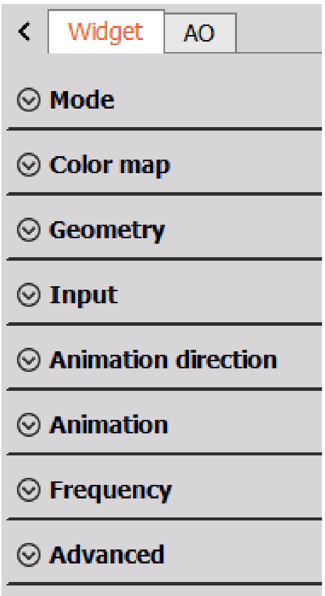
By pressing the CTRL button on the keyboard and left clicking on the mouse, you can add a node to a grid.
By default, the node is set to unmeasured (green color).



Geometry animation of nodes points shown together with a defined background grid.

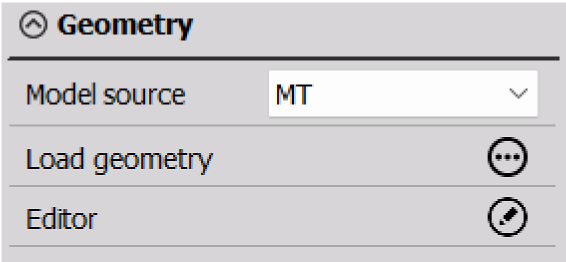
6.6.5 Modal geometry widget properties

The Modal geometry widget has a longer list of widget properties as shown below. These will be described in the following sections.



Collapsed properties sections for the Modal geometry widget.

6.6.5.1 Geometry settings



Geometry section properties of the Modal geometry widget.

Model source
Under the Geometry section the Model source determines which of the available geometries that will be used.

If you have multiple applications that include the use of a geometry, then you can select between which one of them to animate.

For example, if you work with the Time ODS module and you have created a geometry in the Time ODS module setup, then you can select to use it here under Modal source.
If you haven't created a geometry already in some module then you can select the User model and then Load or create a new geometry for that specific widget.

Load and edit geometries
Geometry can be loaded from UNV file format or Edited manually.

- Load UNV - Loads structure data from external UNV (universal file format) file
- Edit - Opens Modal Geometry/UNV editor. The Editor is described under the section UNV Editor.

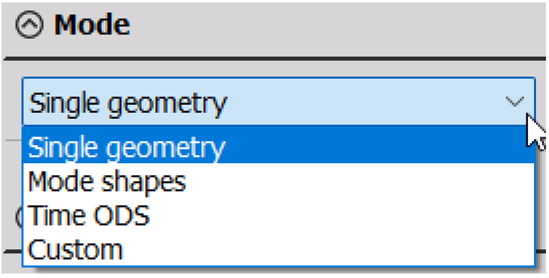
Mouse controls on the geometry:

- Left click: rotate structure
- Right click: translate structure
- Left+Right click: zoom
- Mouse wheel: zoom

6.6.5.2 Widget view mode settings

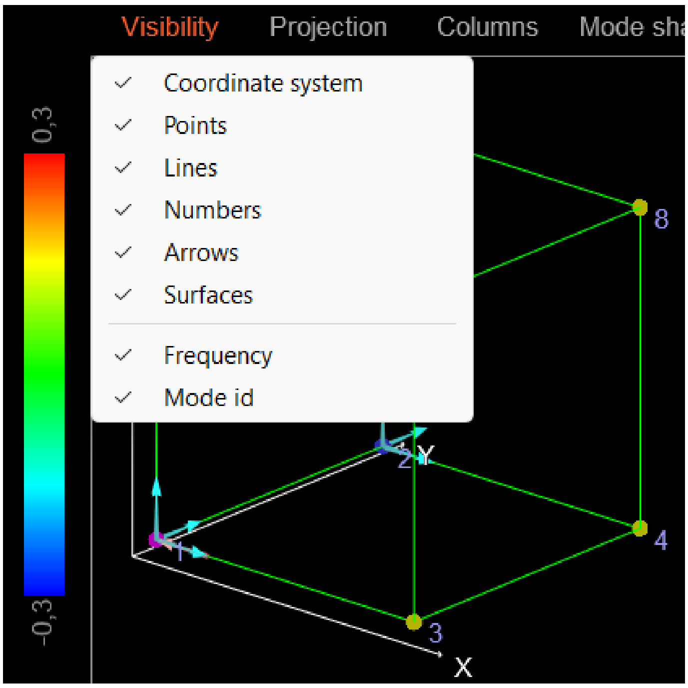
The modal geometry widget view settings found in the header of the widget. The view settings are dependent on the selected view Mode setting. The available view Modes will depend on which modules that are included in the current used setup. Some of them are:

- Single geometry
- Mode shapes
- Time ODS
- Custom



View Mode options for a specific setup.

Visibility
In common for all view Modes are the widget Visibility settings:



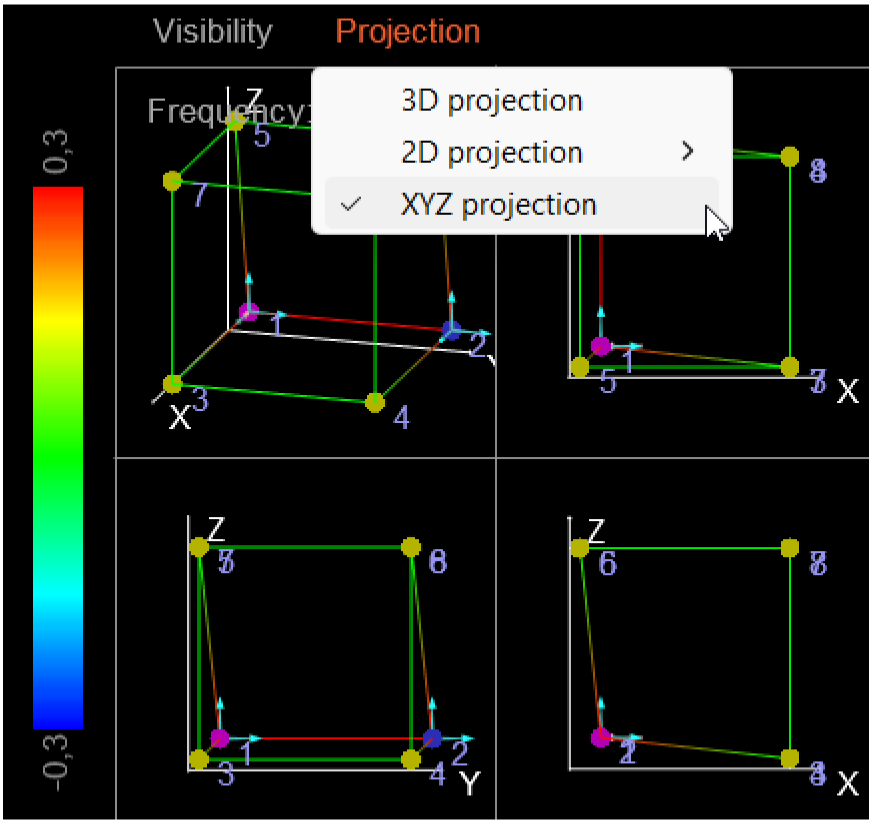
Visibility options available for the Modal geometry widget.

Icons in the Visibility section are used to enable/disable the items listed below:

- Coordinate system - The global coordinate system
- Points - Node points
- Lines - Tracelines, that connects nodes
- Numbers - Node IDs
- Arrows - Orientation arrows for the current measured group of DOFs
- Surfaces - Defined surfaces
- Frequency - The frequency related to current animation
- Mode ID - The mode shape number (only shown for the Mode shapes view Mode)

Projection

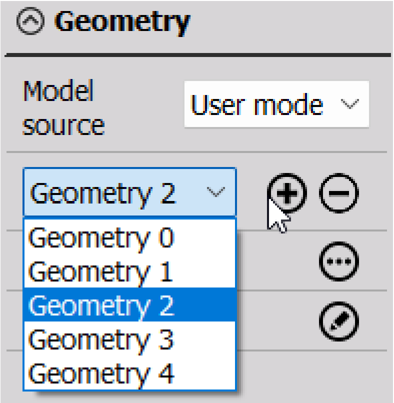
Depending on the view Mode, different projections are possible. For example, when selecting Single geometry view Mode, then both 3D, 2D, and multiple XYZ projections are available as shown below:



Projection options in a Modal geometry widget when Single geometry view Mode is selected.

Whereas for the Mode shapes view mode the multiple XYZ projections are exchanged with multiple mode shapes animated at the same time.

By using the Custom Mode you can have multiple different geometries in a single widget, where you can select the Model Source for each added geometry:

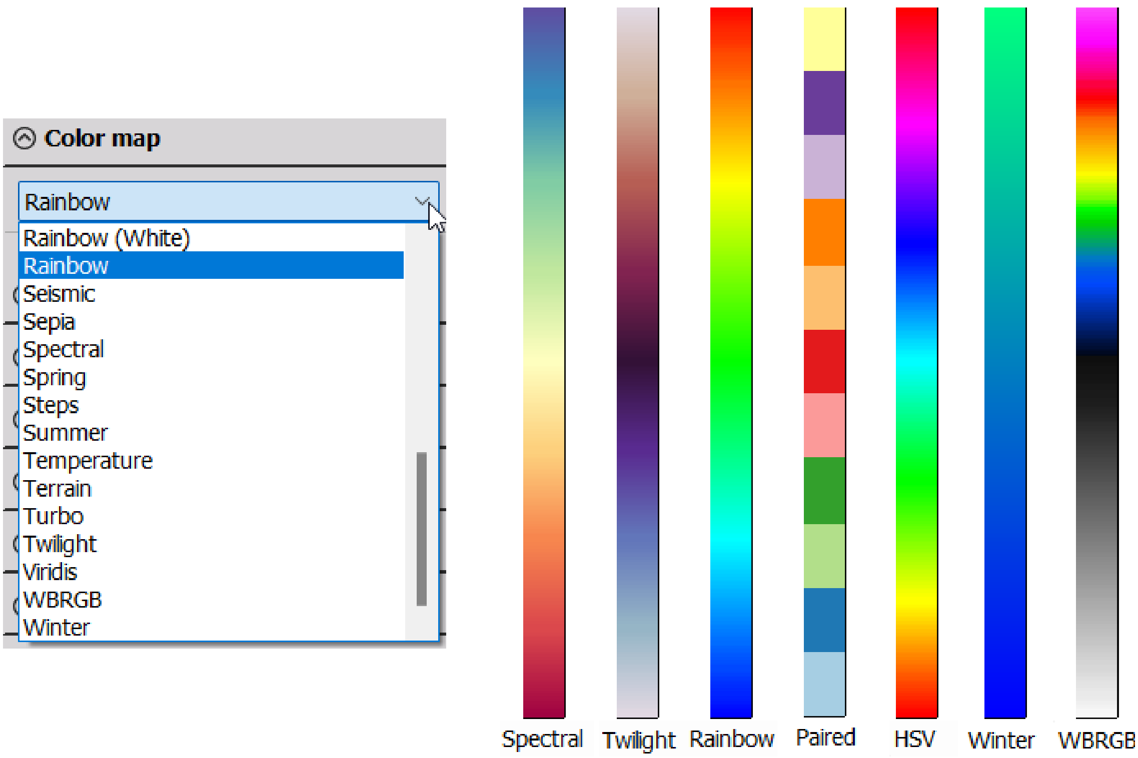


When User mode is selected as Model source then multiple geometries can be shown in the same Modal geometry widget.

In most cases the Single geometry view Mode or Mode shapes view Mode is the right one to use.

6.6.5.3 Color map

The color map property defines the colors used across the animated deflection interval. A wider range of color maps can be chosen between, and some of them are illustrated in the picture below:

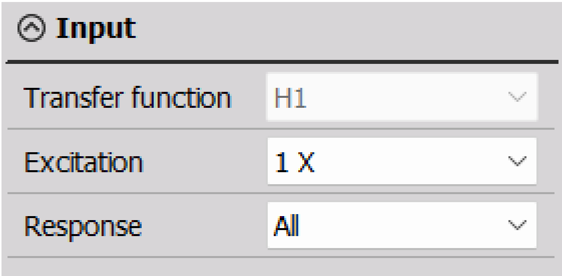


Color map options for how relative deflection levels will be colored on the animation.

Rainbow is selected as the default Color map.

6.6.5.4 Input

The Input settings determine which data results that should be used for the animation.
First, the Transfer function setting is used to select which function type to use. This could e.g. be FRF H1, FRF H2, ODS FRF, or Mode shape.
If you only have results for one of the supported function types then that will be shown automatically:



Input settings for the Modal geometry widget. 'All' DOFs of the type Excitation or Response will be animated relative to the specific selected DOF of the opposite type.

The Excitation and Response drop-down properties determine the group of DOFs to animate and which phase reference that will be used.

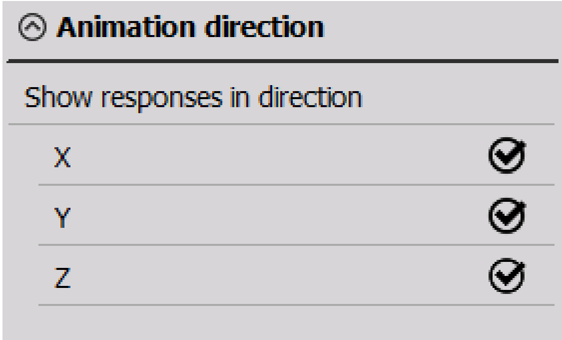
For example, in the picture above the Input settings are set to animate All responses relatively to the phase of the Excitation at Node ID 1 in the X direction.

Note:
For mode shapes the Input settings are disabled since mode shapes can use all Excitation- and Response measurement for estimation of modal models including the mode shapes. The modal analysis estimation process can use the phase information from multiple reference DOFs to determine one model, and hereby both All Excitations and All Responses are used.

6.6.5.5 Animation direction

The Animation direction gives you the ability to visualize the animation in a reduced number of directions.

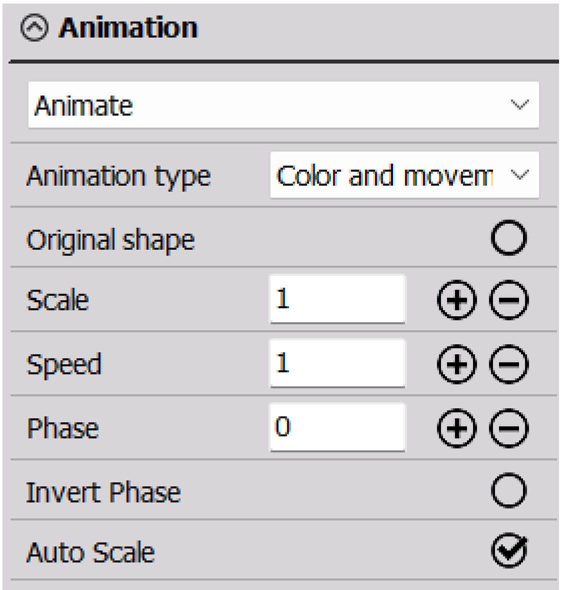
If All Responses have been selected under the Input section, then it will be the response DOFs that you reduce the animation directions for. In the same way, if All Excitations have been selected under the Input section, then it will be the excitation DOFs that you reduce the animation directions for.



Animation direction settings for the Modal geometry widget. Selected directions will be used for animation movements.

6.6.5.6 Animation

At the Animation section you have different ways to manage how the geometry will be animated:



Animation settings for the modal geometry widget.

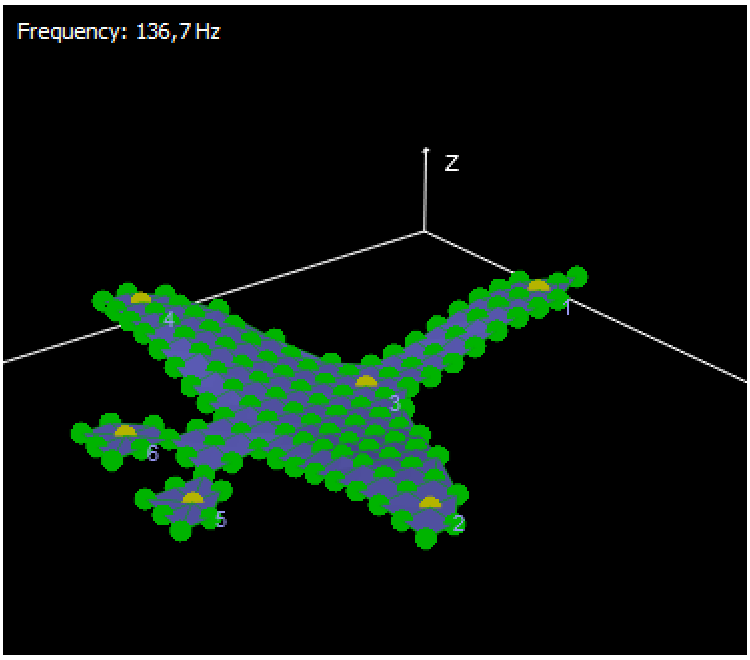
First you can select between if you want the geometry to move or stand-still at a fixed position. You can select between:

- Animate - structure will be moving/animating
- Max Shape - the geometry is fixed at the max deflection phase position
- Manual - the geometry is fixed at a user-defined phase position.

Animation type

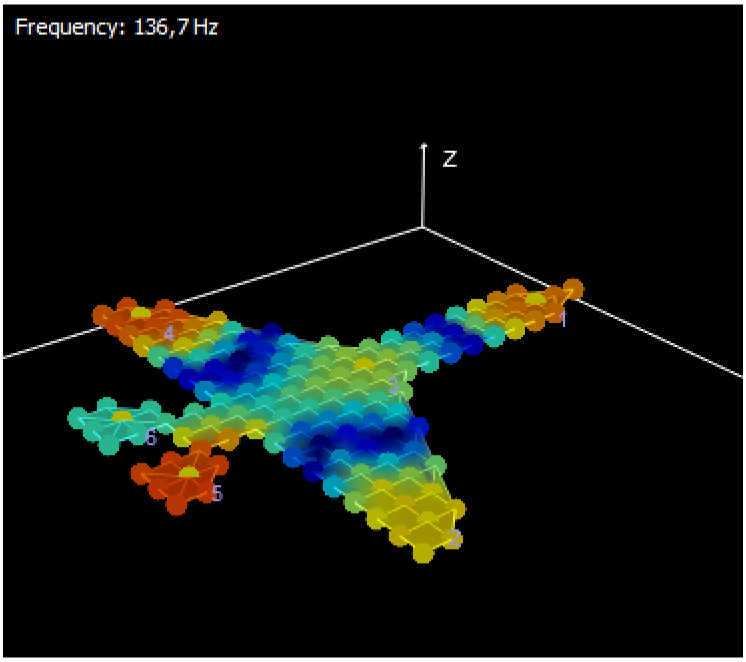
The animation can be selected in different representations:

Movement:



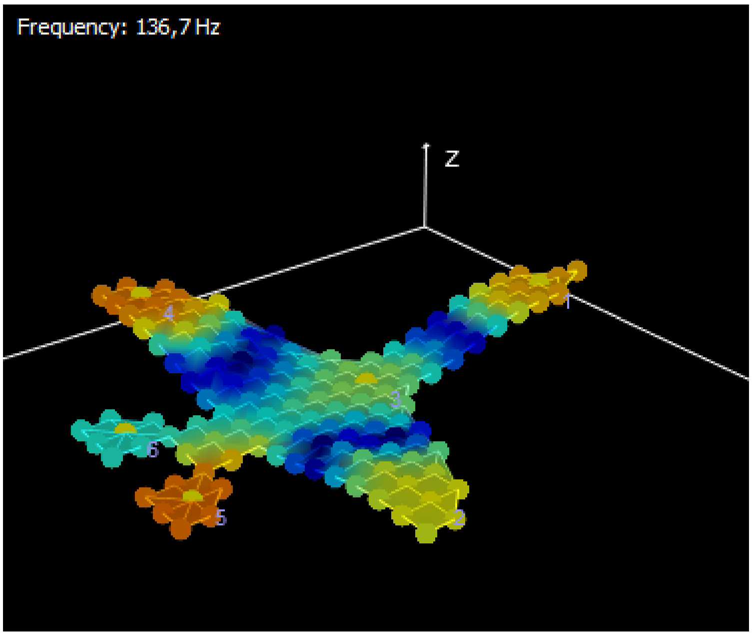
Animation type: Movement.

Color:



Animation type: Color..

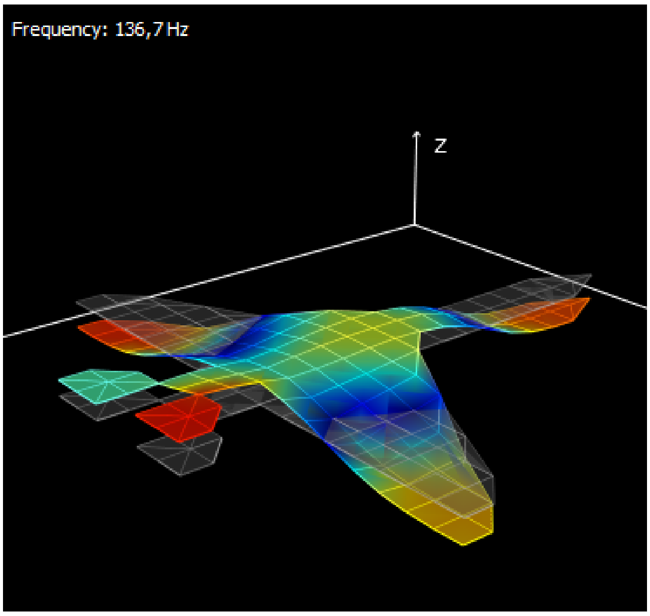
Color and movement:



Animation type: Color and movement .

Show original shape

By checking the Show original shape checkbox, the undeformed structure will be shown (grayed out) at the same time as deformed one.



By selecting 'Show original shape' a shadow version of the geometry will be visualized in a fixed position together with the animation.

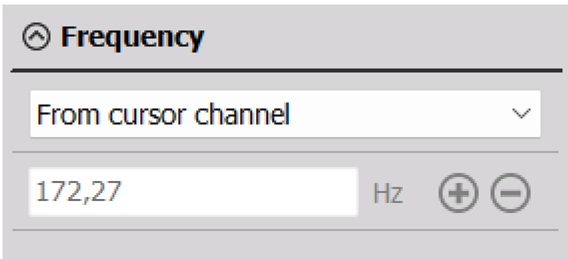
Scale, Speed, and Phase
Scale and Speed values define how fast and how much nodes should move. Default value for both fields is 1.

The Phase can be used to look at the structure at a certain deflection position, but it can also be used to align the phase of two different modal geometry animations. For Max Shape animation the Phase parameter is not shown.

Auto-scale
With Auto-scale enabled, the animation will automatically scale the color map and deflections such that the geometry moves with similar amplitudes when changing what should be animated - for example, when changing the frequency for a MT animation. This is often used for FRF and mode shape animations where you animate relative magnitude deflection levels.

If the Auto-scale is disabled the color map and deflection range will stay fixed, such that the geometry will vary how much it moved when changing what to animate. This is often used for ODS FRF animations where you animate absolute amplitude deflection levels.

6.6.5.7 Animation at selected frequency



Frequency settings for the Modal geometry widget.

Animation of the structure is done at a defined frequency. This frequency can be defined:

- From cursor channel - animated frequency is taken from yellow cursor on 2D graph
- Manual - manually define animated frequency

6.6.5.7 Advanced

Under the Advanced settings section you can:

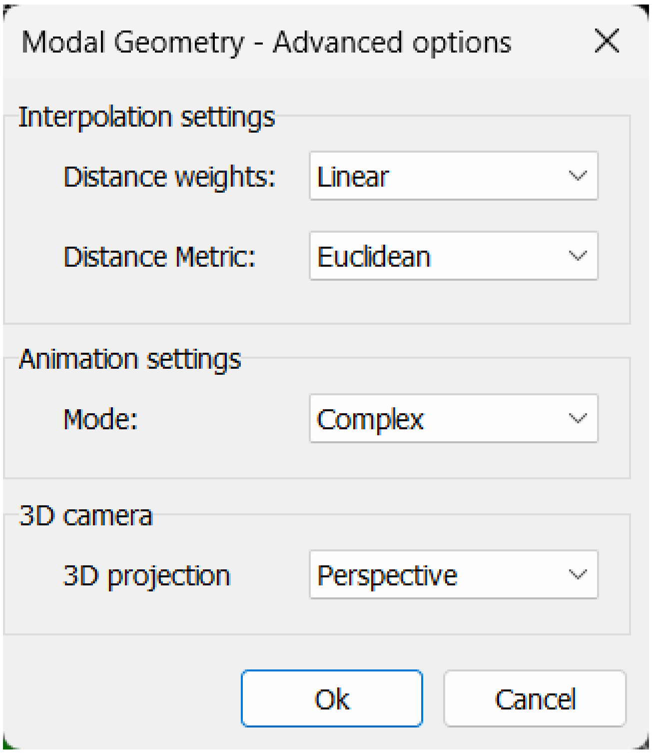
- Modify the animation processing even further under Advanced options,
- Export a video of the animation under Animation export

Advanced section of the Modal geometry widget.

Advanced options

In Modal geometry, also the unmeasured points can be animated. They must be connected with a line to a measured point in order to animate them.

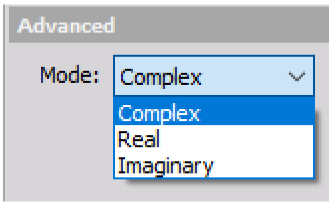
We do the animation of the unmeasured points with interpolation, and the interpolation settings are user-defined.



Advanced animation processing options are found by clicking on the Advanced options button.

In most cases the Distance weights should be set to Quadratic and the Distance Metric to Euclidean, in order to animate the structure in a way that relates the most to real life dynamic movements.

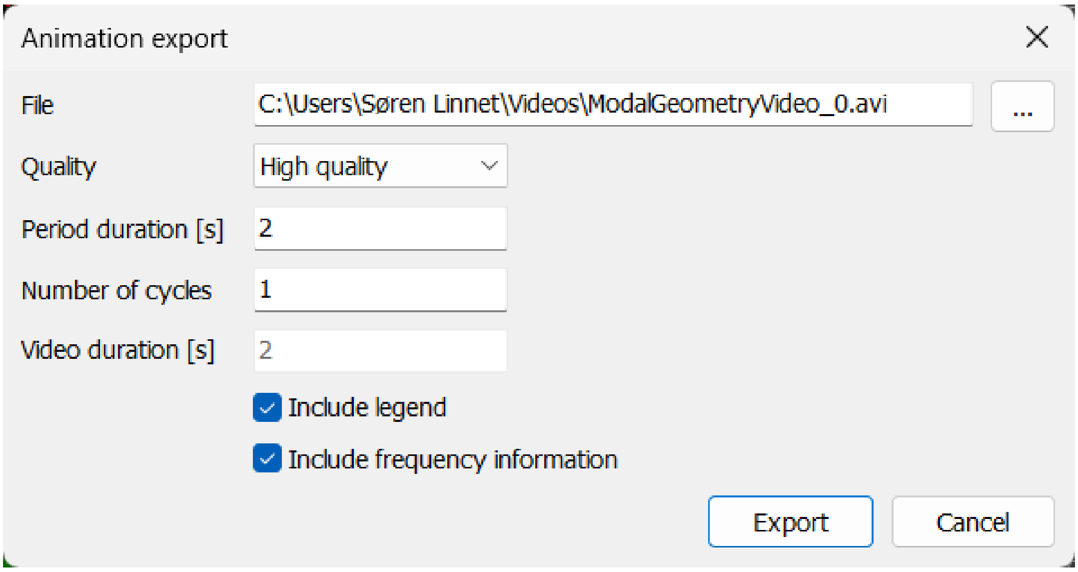
Animation settings FRF's calculated from the Modal test module are complex channels. They contain information about amplitude, phase, real and imaginary parts. To support this, we can also animate the real, imaginary or complex part.



Selection of which parts of the complex source data should be used for animation.

Animation export

The animation can be exported to a video file, which makes it easy to share and use in various presentations.



The animation can be exported to a video using the Animation export feature.

The Period duration will determine the speed of the moving geometry in the animation.
The Video duration indicates the full time length of the video based on Period duration and Number of cycles.

7. Modal test results

7.1 FRF (Frequency Response Function)

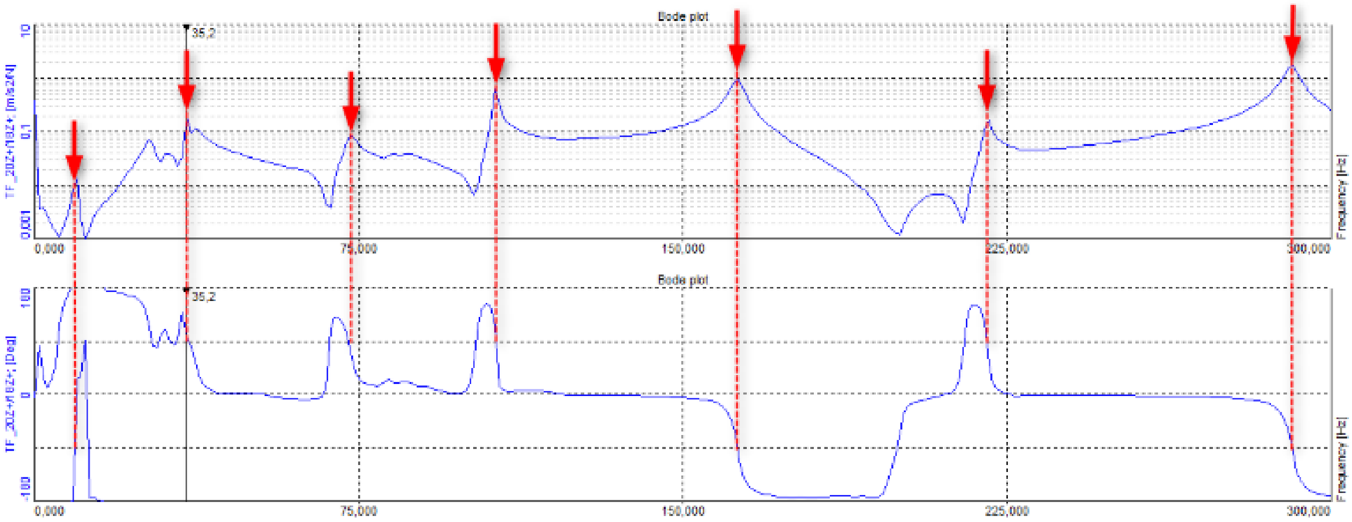
The primary result to extract from Experimental Modal Tests are the Frequency Response Functions (FRFs) between the reference DOFs and all DOFs on the geometry.

FRFs are measures of the relation between output response motion and the input excitation force, and hereby indicate the inherent properties of a linear system.

FRF values are calculated for each FFT frequency component, providing FRF functions over the measured frequency range.

The magnitude of an FRF is often in units [**m/s2/N**] or [**g/lbf**]. At frequencies with high FRF magnitude values, the structure is more sensitive and the output response will be relatively high even at low input force levels. When the FRF magnitude is at a local maximum/peak, and the phase turns 90 degrees at this point, it usually indicates a resonance. This can be validated by inspecting the Coherence.

On the other hand, at frequencies with low FRF magnitude values the structure is more resistant to input forces and the output response will be relatively low even at higher input force levels. Valley locations often indicate anti-resonance frequencies of the structure.



Example of a FRF Frequency Response Function with magnitude (top) and phase (bottom) information across a defined frequency range..

7.2 Coherence

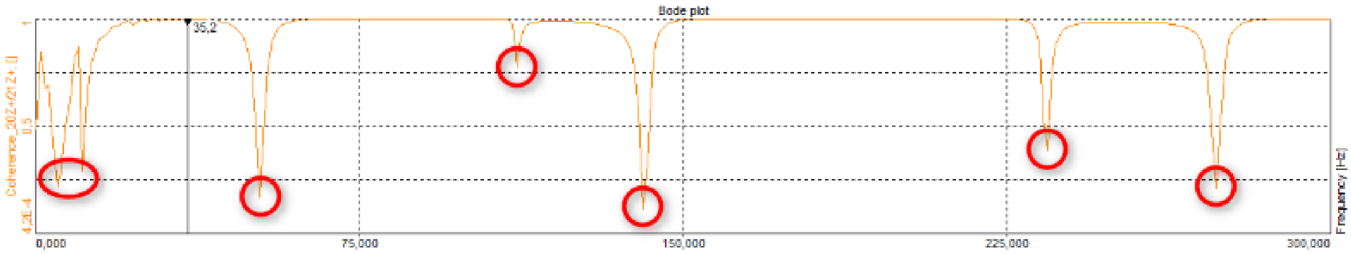
The coherence is used to check the correlation between output spectrum and input spectrum. So you can estimate the power transfer between input and output of a linear system. Easily talking, it shows how good the input and output are related to each other.

The amplitude of the coherence can reach max 1.

Low values indicate a weak relation (e.g. when the excitation spectrum has gaps at certain frequencies), values close to 1 show a representative measurement.

That means, when the transfer function shows a peak, but the coherence is low (red circles in the picture below), it must not necessarily be a real resonance. Maybe the measurement has to be repeated (e.g. with a different hammer tip?), or you can additionally look for the MIF parameter, explained below.

Coherence is a Vector channel, and therefore displayed with a 2D graph instrument. The coherence is calculated separately for each point (e.g. Coherence_3Z/1Z, Coherence_4Z/1Z, ...).



Example of a Coherence function, showing how correlated a pair of response and excitation signals are to each other.

7.3 Mode Indicator Function (MIF)

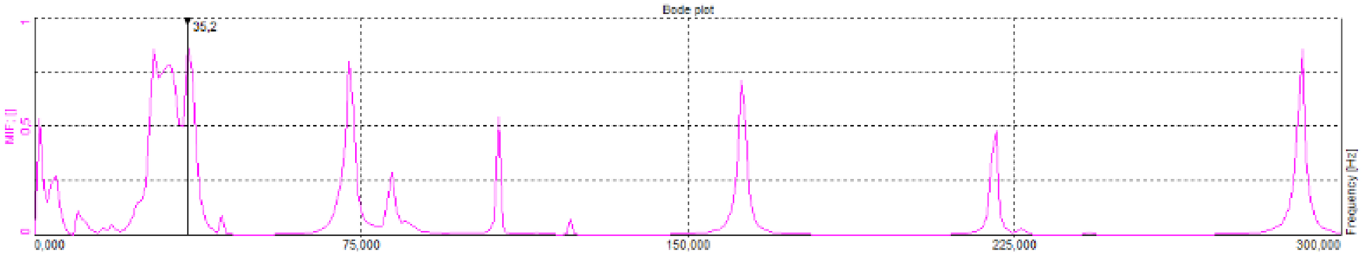
If all parts of a structure are moving sinusoidally with the same frequency (fixed phase relations), this motion is called normal mode. This happens at resonance, or natural frequencies. Depending on the structure, material and boundary conditions, there exist a number of mode shapes (e.g. twisting, bending, half-period, full-period movement...).

These are usually found out by finite elements simulation software, or by experimental measurement and analysis.

In Dewesoft, when the amplitude of the transfer function shows a local maximum, and the phase is turning at this point, it usually indicates a resonance. To be sure, also the Coherence should be checked, as described before. And last, you can look for the MIF (=Mode Indicator Function).

A MIF value close to 1 in Dewesoft indicates a mode shape.
In other software MIF data is often calculated to represent modes at 0 instead of 1, but in Dewesoft we calculated MIF results as 1 - NMIF, where NMIF (Normal MIF) basically takes the real part of the FRFs divided by the magnitude of the FRFs. See also section: 10.1.1 MIF (Mode indicator function)

The spikes shown in the picture below are very likely resonance frequencies. Just click on them and check the movement in the geometry instrument. MIF is a Vector channel, and therefore also displayed with a 2D graph instrument. The MIF is calculated over all transfer functions (all points), therefore is only one channel.

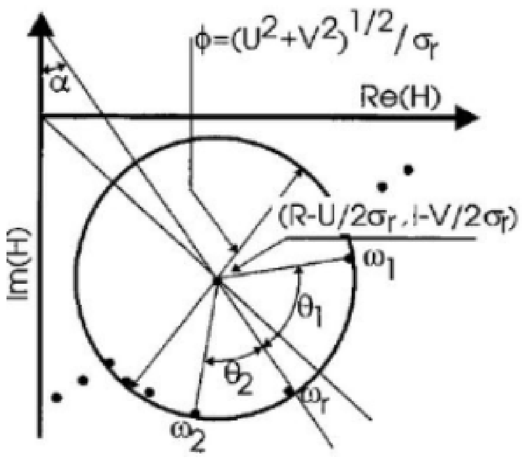


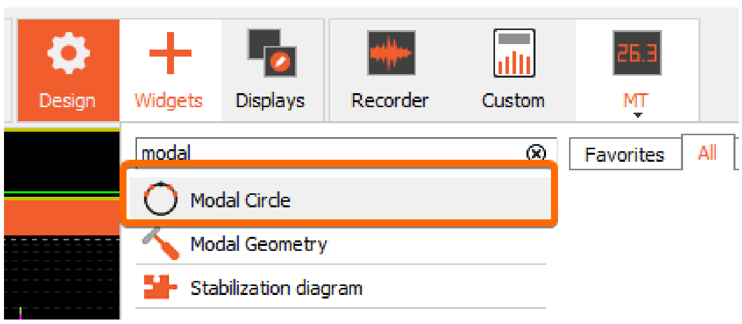
DEWESoft Modal test MIF Mode Indicator Function showing 1 - NMIF values such that a value of 1 indicates a mode.

7.4 Modal circle

Finally, when you are certain the point you are looking at is a resonance, you might want to get it's exact frequency and damping factor. As the FFT can never be that precise (high line resolution needs long calculation time, which is not given when there is a hammer impact), there are some mathematical methods to interpolate.

The method DEWESoft is using, is based on the well-known circle-fit principle. The FFT lines to the right and left side of a peak (so called "neighbor lines") are drawn by real and imaginary parts in the complex coordinate system. A circle is aligned between them with minimum error to each point and the resonance frequency is approximated.



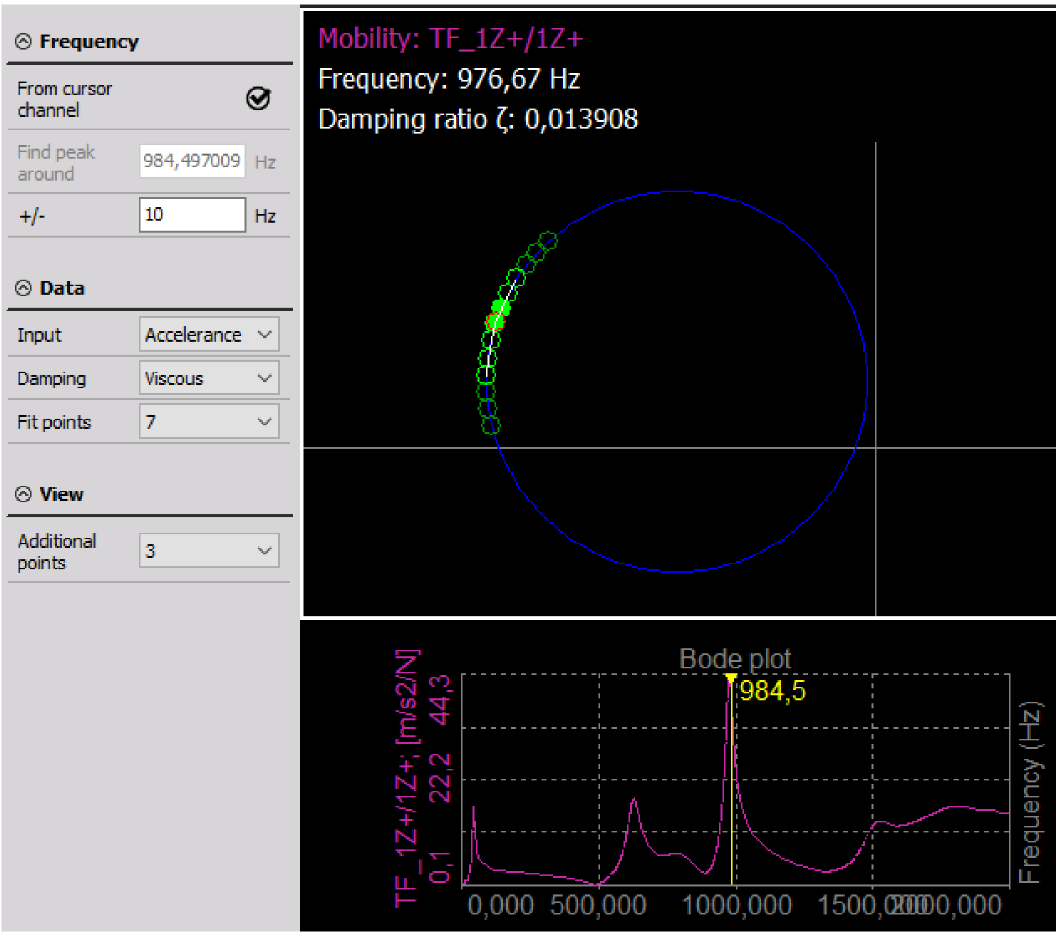


The Modal circle display widget takes a number of FRF lines around a mode line, and performs a circular fit to from which SDOF global modal parameters can be determined, being the resonance frequency and damping coefficient.

In the example below we switched the 2D graph "Graph type" property to "histogram" to make the FFT lines visible.

Imagine, we had a sample rate of 2000 Hz, and 1024 FFT lines, resulting in a line resolution of 0.977 Hz. The peak we are looking at is 73,2 Hz. But it could be in the range of 73,2 Hz +/- 0,977 Hz.

We add the Modal circle from the instrument toolbar (see picture above). The 2D graph is again in "cursor" mode, the modal circle instrument will follow. – By clicking on the peak, at first no resonance peak is found.



The MIF plot is used to determine which peak to do a circular fit on. The number of Fit points (number of spectral lines on the selected FRF function) are used for the circle fit process. The SDOF resonance frequency and damping ratio are obtained and validated based on how well the Fit points are on the blue circle.

- From the cursor channel - the yellow cursor on the 2D graph is taken for frequency point determination.
- Manual - you can manually enter frequency points for the circle fit procedure.
- Peak search (manual mode) - an area in which we will search for a peak for circle fit.
- Neighbour count - a number of neighbors taken into account when doing the circle fit.

8. How to perform modal analysis

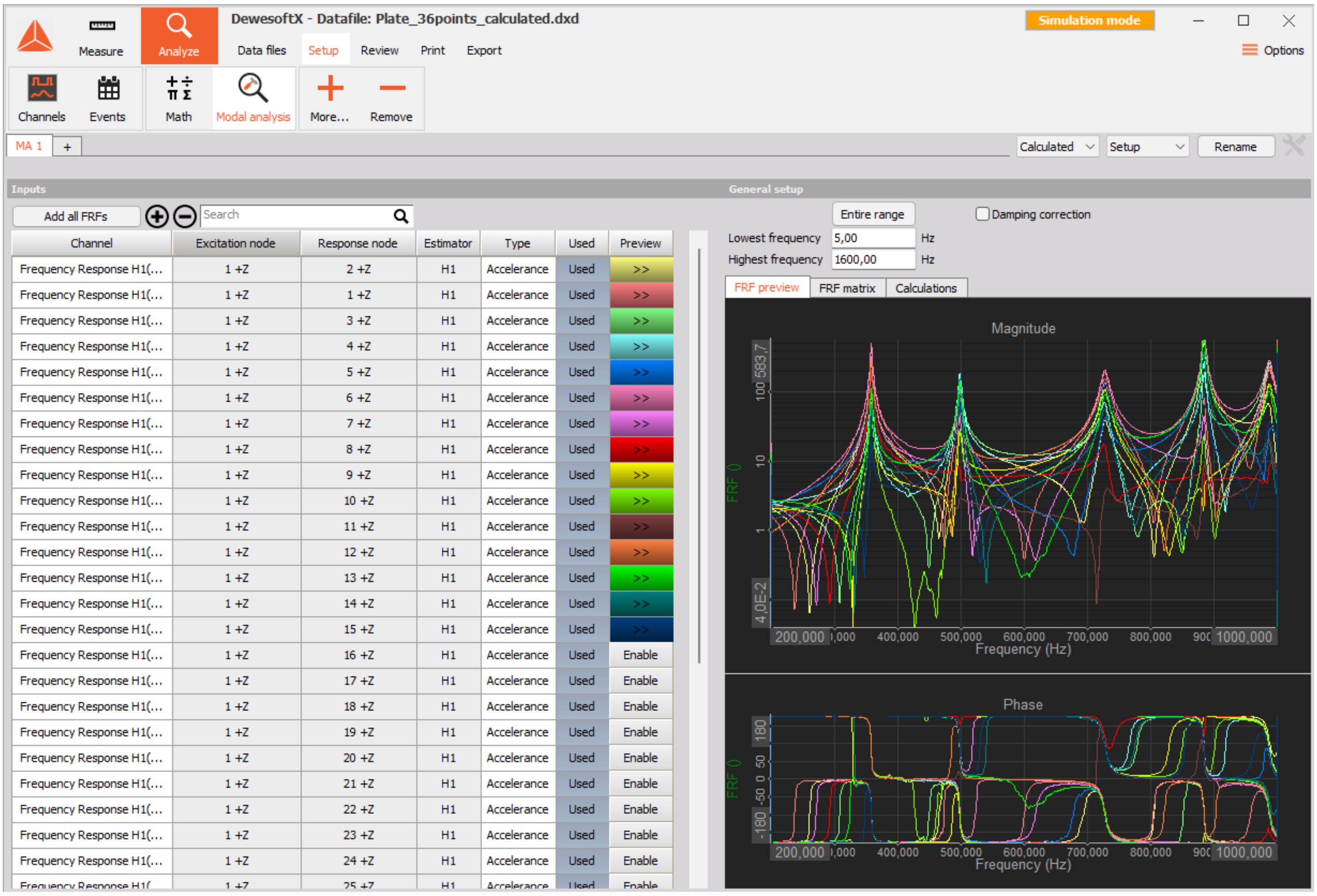
Having acquired the Modal Test data, the next step is to identify the modal parameters (resonance frequencies, damping ratios and mode shapes) by using Parameter Estimation techniques, including Mode Indication Functions (MIFs) and Curve Fitters.

User scenarios for how to perform modal tests and analysis can also be found under section 13. Examples (step-by-step).

8.1 Modal analysis setup

Since the Modal analysis is a post-analysis tool that uses already measured data, the modal analysis setup and analysis is handled in Analyze mode.
Under Analyze, open a data file containing modal test measurements. The FRF results from the Modal test are used for the estimation of the modal parameters in the Modal analysis plugin.

Add the Modal analysis plugin by clicking on the + More.. icon and select Modal analysis.
Below the setup for the Modal analysis plugin is illustrated.



Modal analysis module setup page.

8.1.1 Inputs table

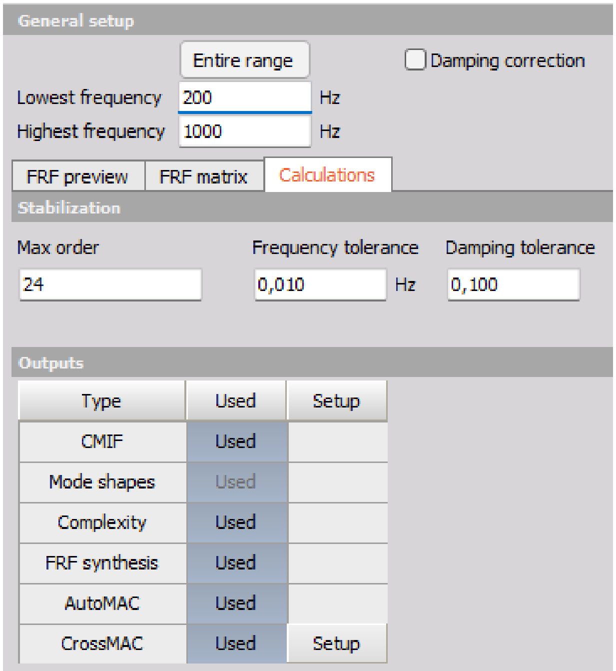
Add specific or all FRFs from the data file by either pressing the + button or the 'Add all FRFs' button. The Inputs table lists all added FRFs and by default all added FRFs are also set to be used for the modal model estimation process.
If some FRFs look very different from the others it might be due to local modes only present at certain DOFs. Such FRFs can be de-selected (set to Unused) and instead used for other estimations that only include those FRFs with such characteristics. You can have multiple Modal analysis instances in parallel to handle more estimations at the same time. This is done by pressing the + tab next to the MA 1 tab.

8.1.2 General setup

Under the Modal analysis - General setup, the frequency range that should be included in the modal estimation can be specified.
The 'Damping correction' should be checked if the Modal test measurements were performed with 'Force + Exponential' time window functions, where the 'Exponential window decay' value should be set to the same as used under the Modal test.

8.1.3 Calculations

Under the Calculation tab settings for the 'Stabilization' plot is shown together with the list of possible output result types provided by the Modal analysis plugin. Outputs will be described in section: [10. Modal analysis results].



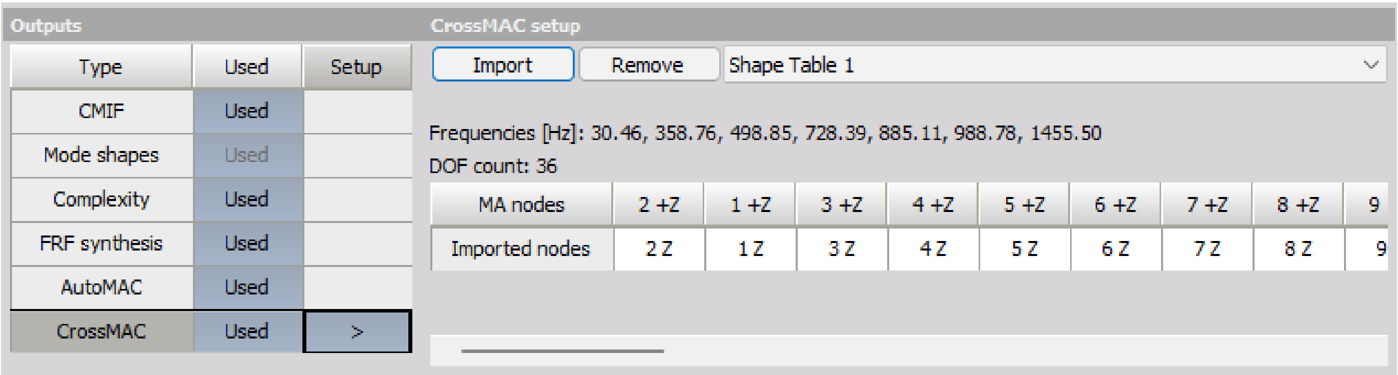
Output results from the Modal analysis module.

Max order determines how many iterations the estimation process will use to fit a series of SDOF systems (the modal model) to represent the information in the selected FRFs.

Frequency and Damping tolerance will determine when the stabilization plot will indicate estimated poles to be stable. For more information see section: 8.2 Using the Stabilization diagram.

8.1.4 CrossMAC setup

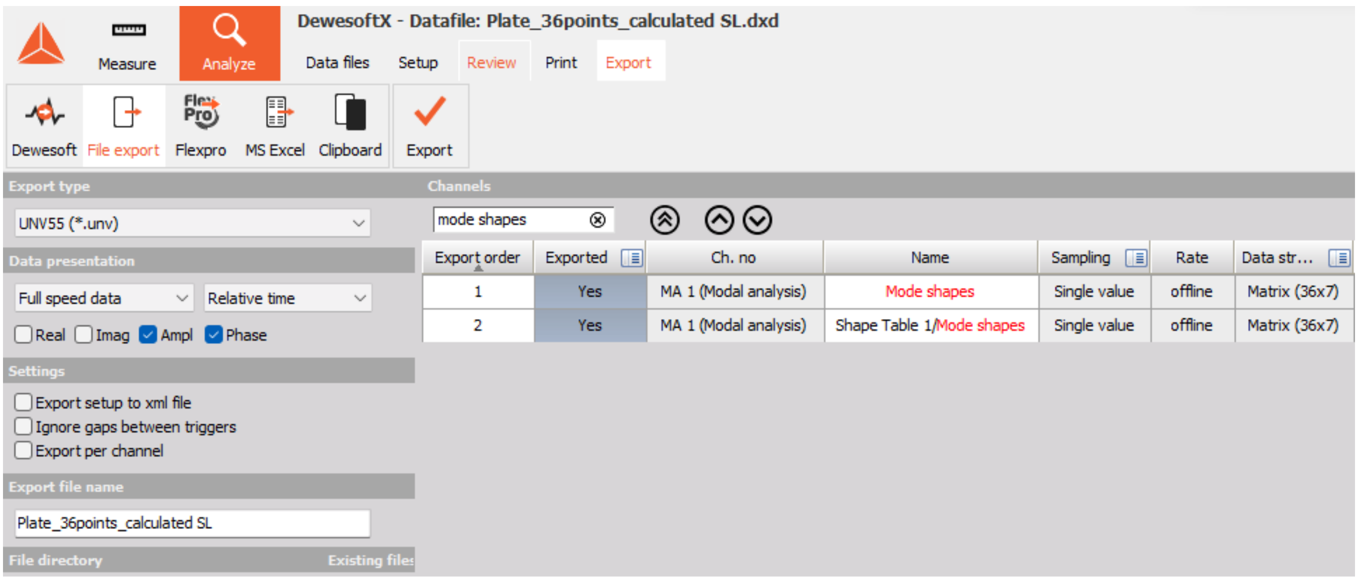
In the Modal analysis plugin it is possible to import other modal models and analyze those in comparison with current estimated modal.
By selecting CrossMAC to be Used, a CrossMAC setup area becomes visible.



CrossMAC settings with a table showing the imported mode shape data.

Modal models can be imported from UNV files having the model data stored in the UNV 55 dataset. After importing a model the included mode frequencies will be shown together with the used number of DOFs and node information shown in the MA nodes table.

It is also possible to export estimated modal models to the UNV 55 file format for them to be used later for crossMAC and other usages in e.g. 3rd. party software like FEM applications.
Modal models can be exported under the 'Export' section in Analyze mode. Select the UNV55 Export type and set the desired 'Mode shapes' to be exported, as shown below:



Settings used for exporting mode shape data using UNV dataset 55.

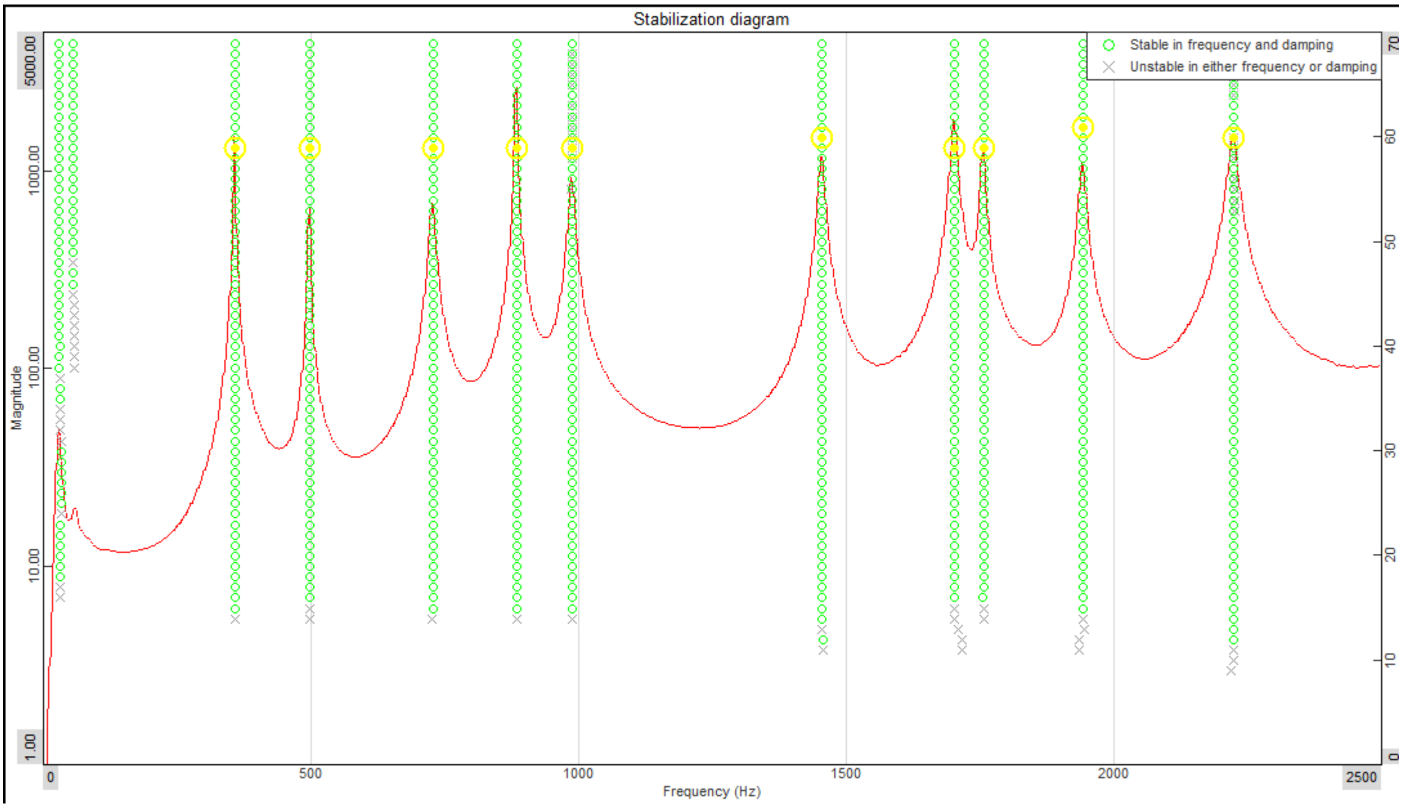
8.2 Using the Stabilization diagram

When going from Modal analysis Setuo to the Review and the Estimation display layout has been selected, the first step is to select stable poles on the Stabilization Diagram (SD).
If no poles are shown on the SD then click on 'Recalculate'.

Click and select a stable pole from each desired mode on the Stabilization Diagram. If not 'Auto-recalculate' is checked then press recalculate, and the modal model will get estimated based on those selected poles.

In the stabilization diagram stable poles will represent consistent modes. The poles consist of the modal frequency and damping. Increasing the Order of the estimation in the Setup will also increase the number of estimated poles. When the estimated poles begin to only change a little between individual neighbor orders, then the poles are said to be stable.

The Modal Analysis module provides user-defined tolerance values that can be set to determine pole stability. Such tolerances can be specified for the frequency and damping individually on the Setup page.



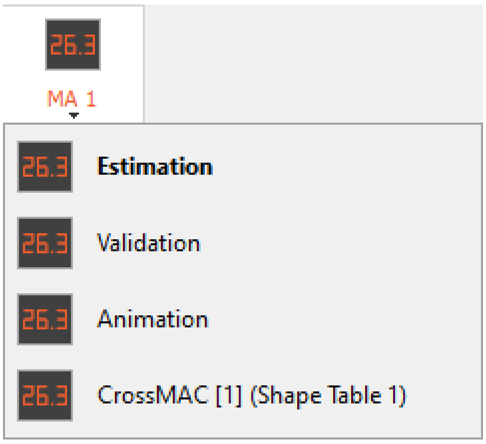
*Example of the Stabilization diagram widget used for Modal analysis. Straight **green circle** lines indicate well defined modes. The user-selected poles shown with **yellow circles** are used for estimation of the MDOF modal parameters. The **red curve** is a complex mode indicator function, CMIF, which helps identify the modes..*

9. Modal analysis review and visualization

9.1 Auto-generated displays

For an easier start, DEWESoft also offers auto-generated displays for Modal analysis, which already come with the most often used instruments and an arrangement that makes sense for the according type of application.

With the Modal analysis module added, usually when switching to Review mode, there should already appear a display group, called “MA 1”. If the Modal analysis setup tab instance name was modified that name will also be used as the display group name.



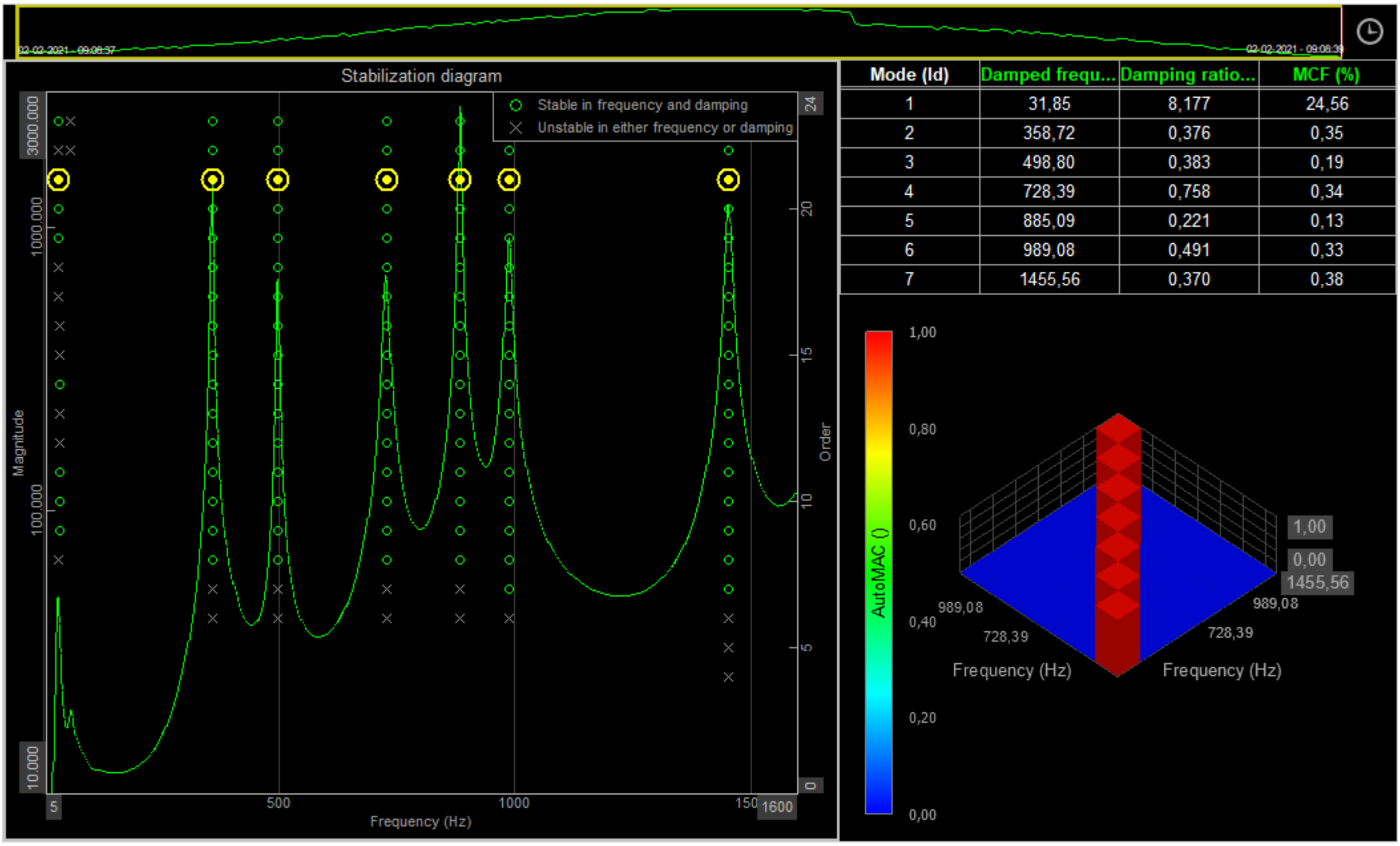
Pre-defined Modal analysis display templates.

If that is not the case, please go to Settings → User interface and enable the “Auto generate displays” checkbox. Then add a new Modal analysis module and go to Review to see the MA display group.

If later on changes are made to the Modal analysis setup that will affect the displays then right click on the display group and press Rebuild. Then the display layout will update to the newest settings.

9.2 Estimation display

The first predefined Modal analysis sub-display is 'Estimation'. Estimation is used to start the modal estimation process by having a larger Stabilization diagram which is used to select poles at. After poles for the relevant modes are selected click on 'Recalculate' to determine the modal model.



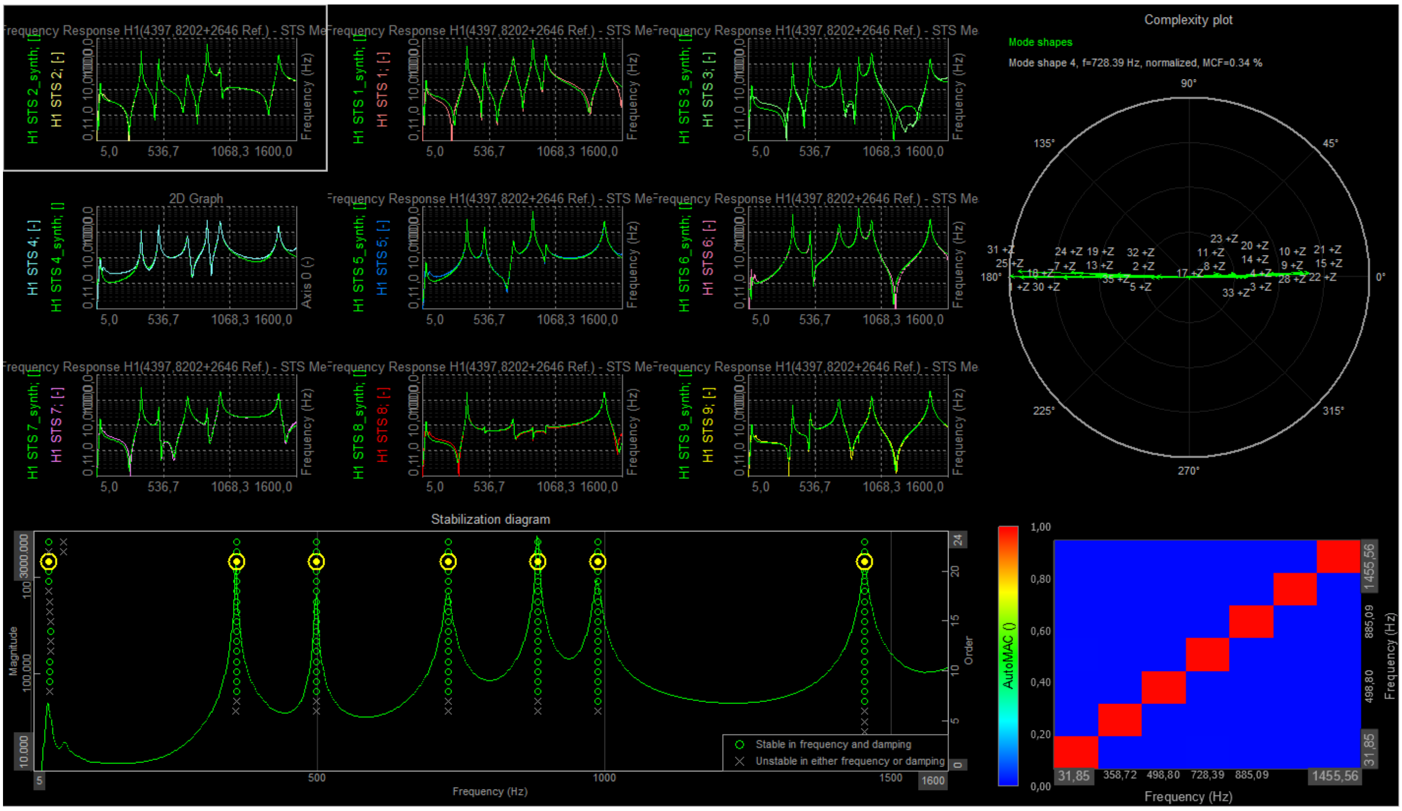
*Pre-defined **Estimation** display template for modal analysis. Poles are selected on the stabilization diagram, and then AutoMAC and modal parameters are inspected after Recalculation.*

After recalculating, the estimated global modal parameters being Damped resonance frequencies, Damping ratios are listed for all selected modes in a table in the right side of the display. Also the Mode Complexity Factor (MCF) is listed in the table.

In the lower right the AutoMAC are illustrating how well the different modes are uncoupled from each other in the estimated model. For more information about AutoMAC see section: 10.5 AutoMAC.

9.3 Validation display

After finishing the estimation process, go to the next pre-defined Modal analysis sub-display called 'Validation'. This display is configured with widgets representing the quality of the estimated model.



*Pre-defined **Validation** display template for modal analysis. Selected poles for relevant modes can be changed on the stabilization diagram to optimize Synthesized FRFs curvefits, while inspecting the AutoMAC and the mode complexities.*

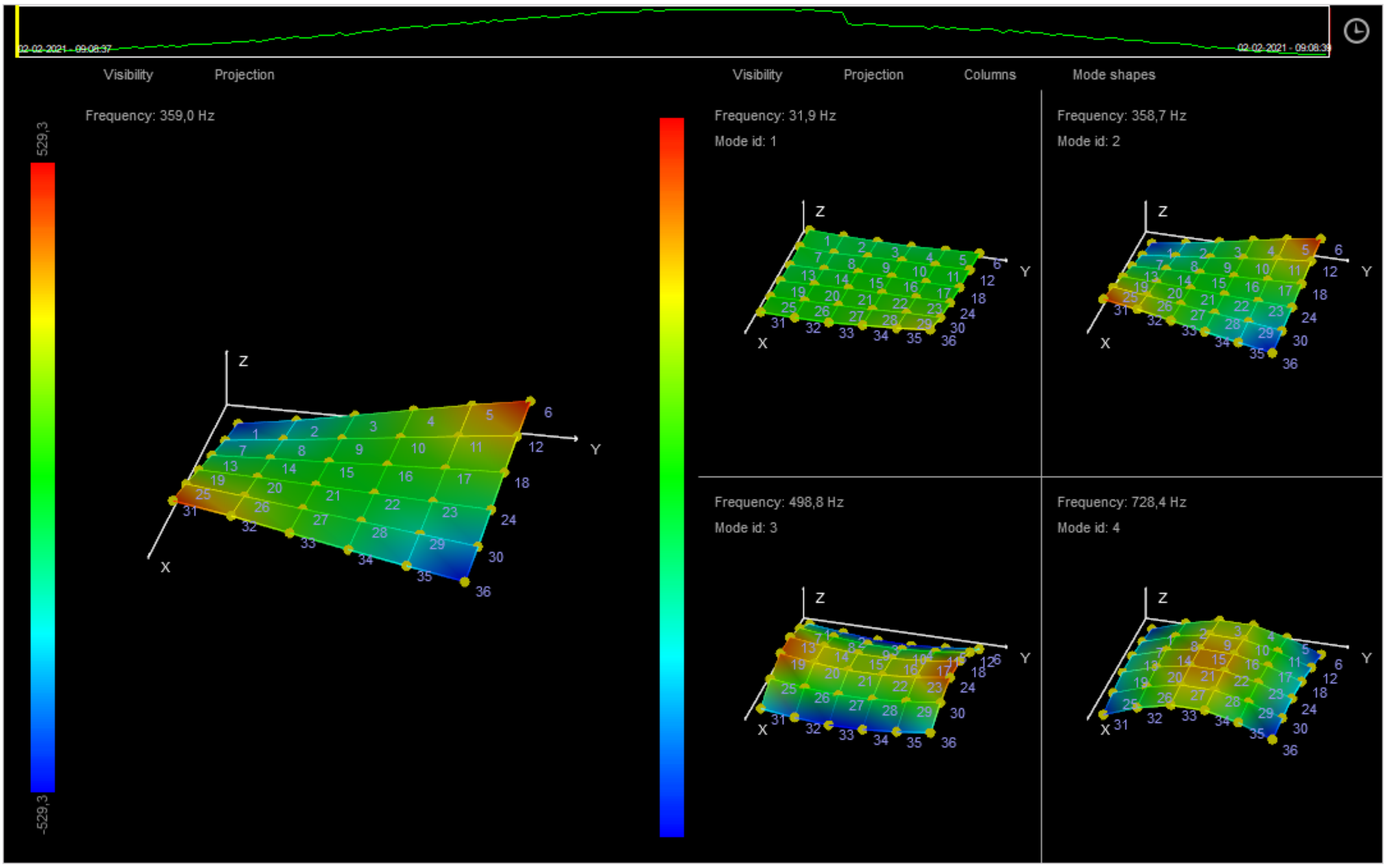
In the upper left a group of 2D graphs show measured FRFs overlaid with model synthesized FRFs. Comparing FRFs with synthesized FRFs can indicate if all modes are represented in the modal or not, and how well they describe the measured FRFs.

In the upper right a Complexity plot shows the relative phase difference between the individual DOFs. A straight line with DOFs at 0 or 180 degrees between each other indicates a mode with low complexity where all DOFs vibrate like a standing wave. For more information about complexity plots see the section: 10.3 Complexity.

In order to overview what happens to the synthesized FRFs and the complexity when selected poles get modified, the stabilization diagram and AutoMAC is shown again at the bottom of the display.
By clicking poles on and off and recalculating the modal model, the synthesized FRF and complexity results will update.

9.3 Animation display

When the quality of the modal model has been validated, the estimated mode shapes can be seen animated under the pre-defined sub-display 'Animation'.



*Pre-defined **Animation** display template for modal analysis. Estimated mode shapes (right-side animations) are compared to the measured FRF deflection shapes (left-side animation). The mode shapes can all be viewed at once and verified one-by-one in relation to the measured deflection shapes.*

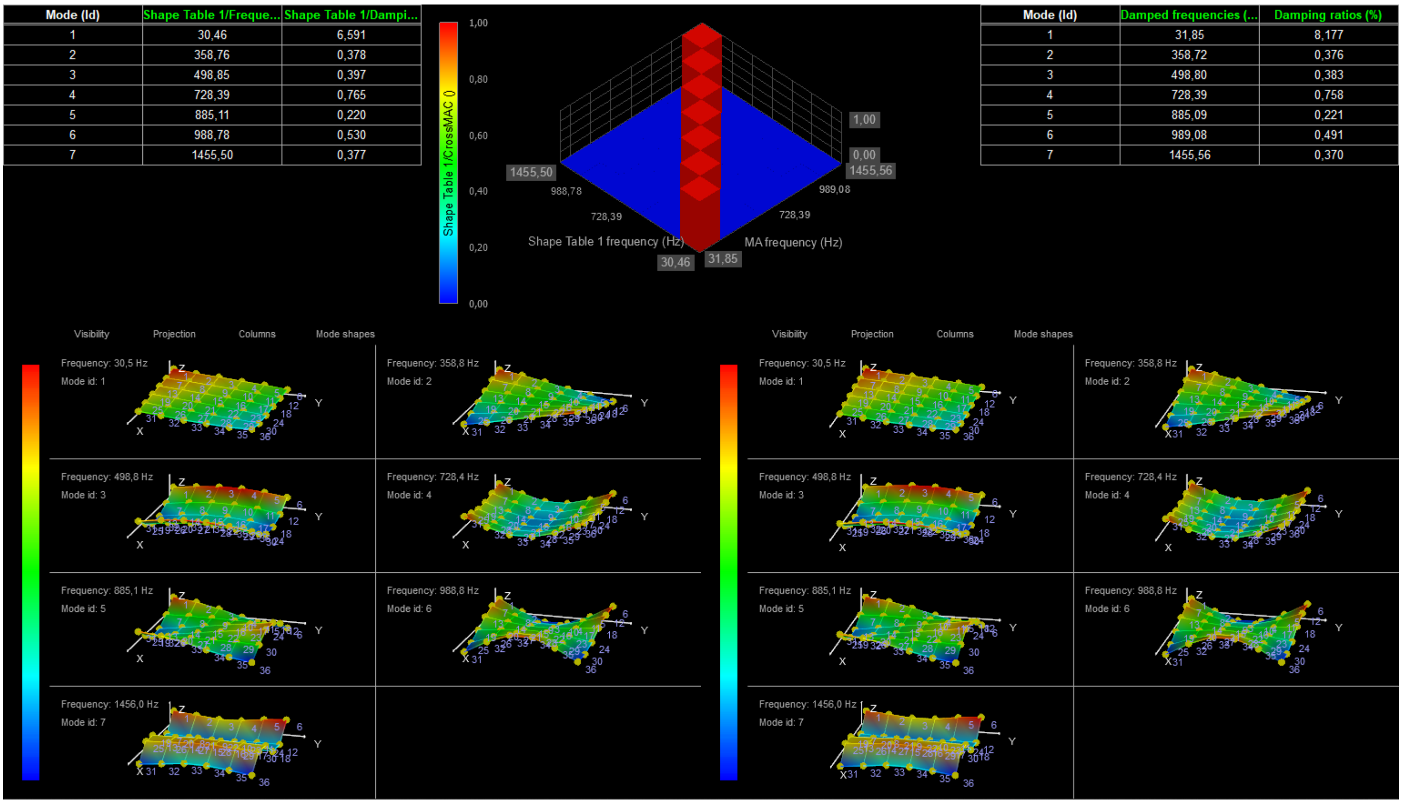
In the Animation display two different geometry widgets are added.
The geometry to the left side is animating the deflection shape based on information from the measured FRFs. The frequency which the deflection shape is based on can be set manually under the geometry properties, or it can be linked to a cursor channel in another graph e.g. the ordinary MIF from MT.
The geometries to the right side are animating one or multiple of the estimated mode shapes.

By comparing the measured deflection shapes at the resonances with the estimated mode shapes can both give an overview of how the modes are looking and how well the estimated mode shapes mimic the measured dynamics. It will hereby be possible to determine which modes are e.g. bending modes and torsional modes.

9.4 CrossMAC displays

If other modal models have been imported via the Modal analysis setup for CrossMAC, then pre-defined display layouts for CrossMAC will be available for each pair of models, where the current estimated model is the reference model.
If you later on import models to the setup the MA display group needs to be rebuilt in order to show the new CrossMAC sub-displays. Rebuilding displays is done by right clicking on the MA display icon and press Rebuild.

In the display layout information about the two models are shown in each side and the CrossMAC between them is shown in the top middle.



*Pre-defined **CrossMAC** display template for modal analysis. Estimated mode shapes are compared to another estimation of the same structure. The modal parameters are shown for each model. If the CrossMAC indicates high diagonal correlation between the two estimated models, that strengthens the model validity and can be used to verify simulated models created with 3rd party FEM software.*

10. Modal analysis results

In the Modal analysis plugin the modal parameters are always available as output results - Those being the **Damped resonance frequencies**, the **Damping ratios** and the **Mode shapes**, for all estimated modes.

Next to these modal parameter results the following outputs are available to be extracted as well. These outputs are all used to help validate the quality of the estimated modal model.

10.1 CMIF (Complex Mode Indicator Function)

Complex Mode Indicator Functions (CMIF), have one function for each reference DOF included (poly reference) and can detect closely coupled modes with repeated roots.

The CMIF is by default shown in the Stabilization Diagram (or SD) to help identify the relevant modes.

CMIF is based on Singular Value Decomposition (SVD) of the FRF functions to identify all modes included in the model test measurements.

The CMIF functions have peaks at resonances - indicating poles of the DUT.

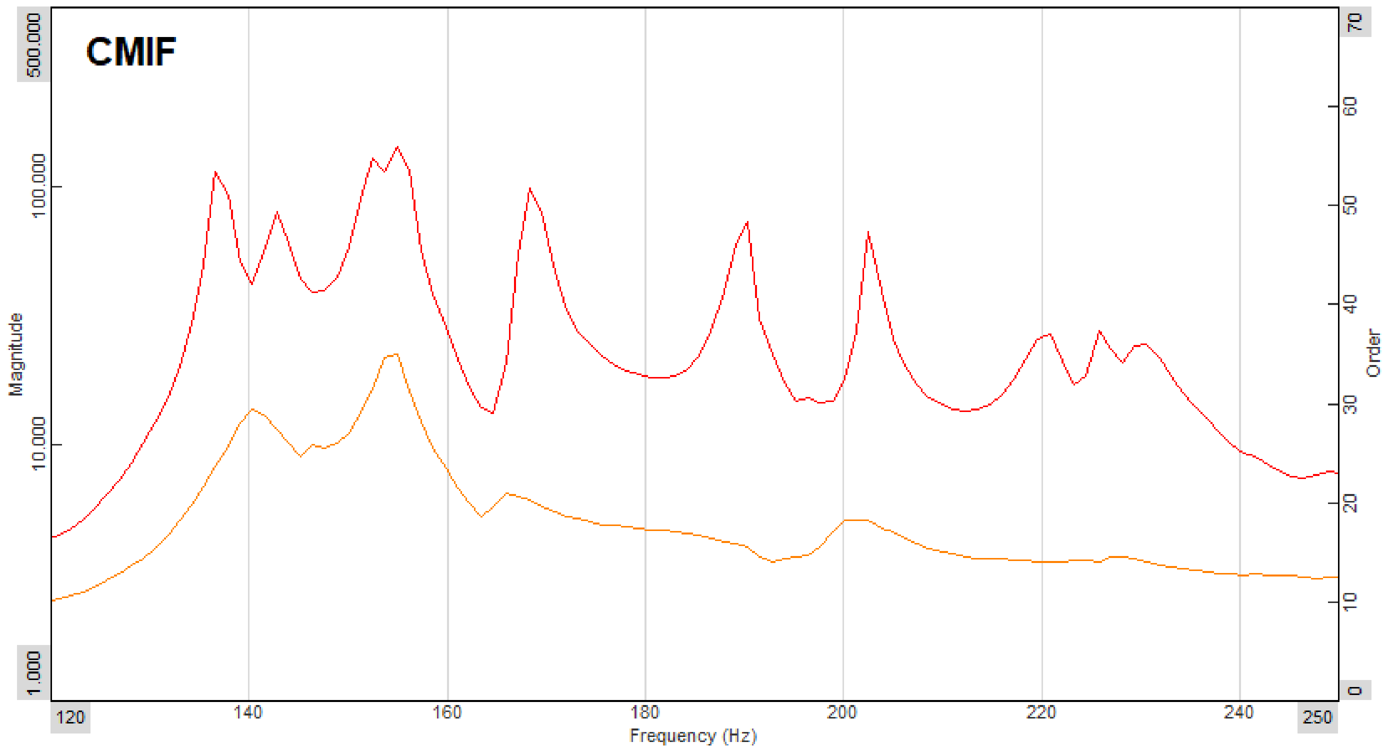
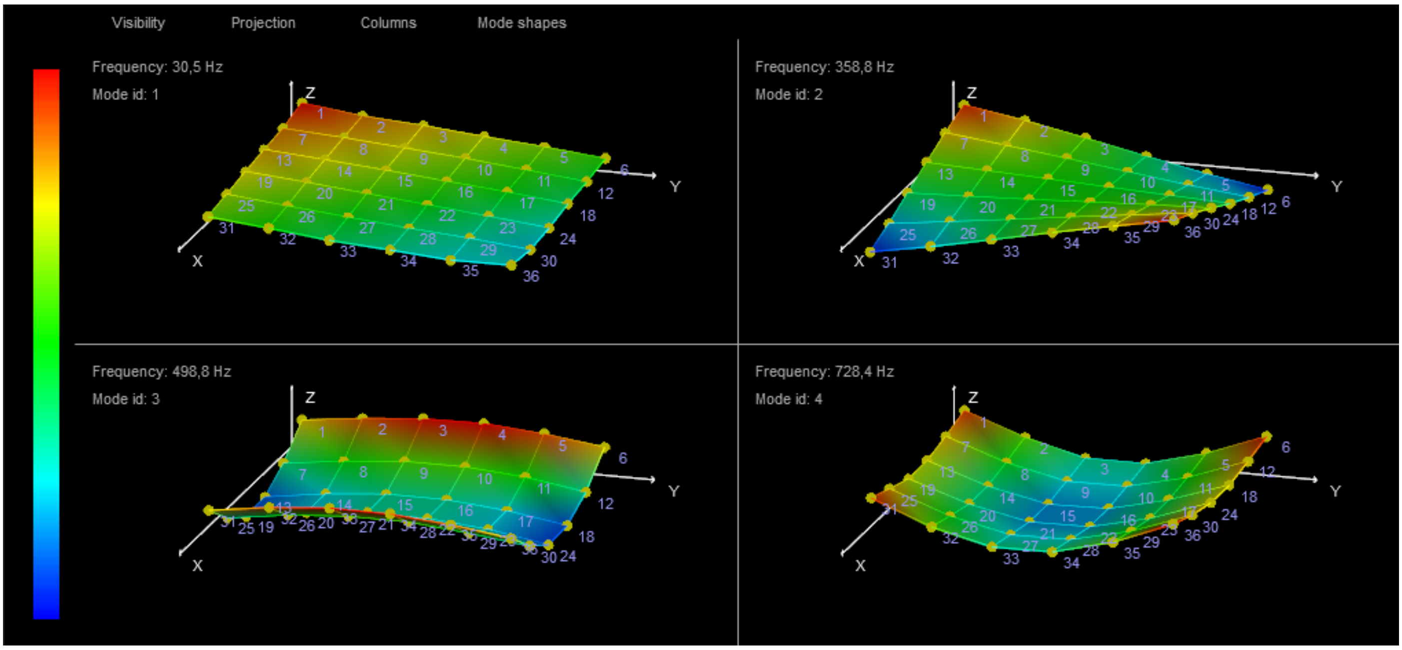


Illustration of Complex Mode Indicator Functions, CMIF. CMIF will create one curve per reference DOF used. Frequency ranges where more than one CMIF curve have peaks indicate multiple modes being so closely coupled that multiple reference DOFs are required to separate the mode information between them.

10.2 Mode Shapes

The mode shape result provides complex values used to represent the shape behavior of each mode. The complex values contain the phase information at each DOF for each mode (DOF vs. mode values). In the picture below mode shapes for 4 different modes are animated base on the complex mode shape data:



Example of estimated mode shapes. Different from the measured MT deflection shapes, the MA estimated mode shapes are only defined for the specific resonance frequencies. Like the global modal parameters the mode shapes are determined to imitate all used FRFs the best.

The mode shape is a Local modal parameter - meaning that the values for the mode shape is different for each DOF.
This is different from the damped resonance frequency and damping ratio which are global modal parameters - meaning that these values are the same for all DOFs - E.g. the resonance frequency is the same over the whole structure.

Since the mode shape is a local parameter it contains values based on each DOF. The full mode shape information can be shown in a 2D/3D table widget where the rows are modes and the columns are DOFs.

The mode shape values are determined from the global modal parameters together with the FRFs for all DOFs, in order to calculate the residues.

10.3 Complexity

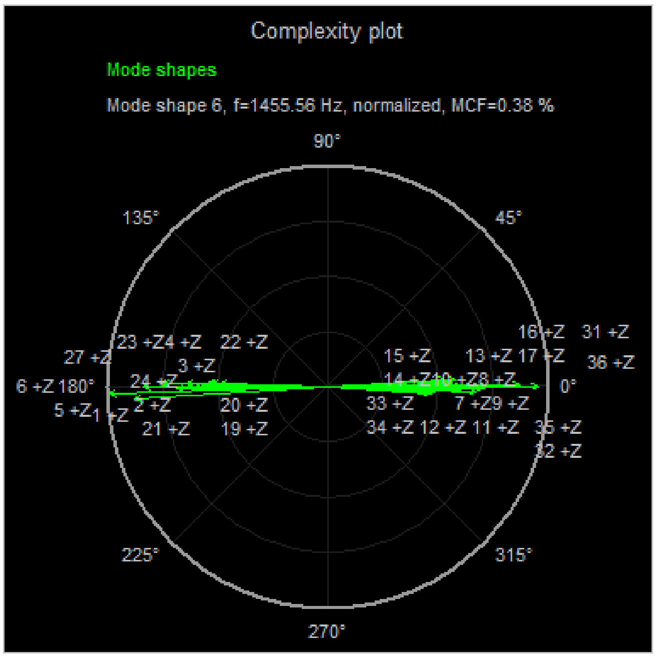
The Mode Complexity Factor (MCF) indicates how well all the DOFs for a given mode deflects totally in or out of phase compared to each other.
If all DOFs vibrate with a 0 or 180 degrees phase difference between each other the complexity or MCF is low, around 0 %.
If the DOFs vibrate with other phases relative to each other the MCF is higher.

High complexity can occur due to:

- Non-proportional damping - e.g. due to non-linearities.
- Bad measurements or poor modal parameter estimation.
- Inconsistent data - e.g. due to time variant conditions.

The mode complexity can be shown in Dewesoft both in a 2D/3D table and in the Complexity plot widget, as shown below.

Mode (Id)	MCF (%)
1	0,35
2	0,20
3	0,34
4	0,13
5	0,32
6	0,38



*Example of modal complexities of estimated mode shapes. The **table** shows the complexity for each estimated mode shape. The **complexity plot** provides a visualization of the complexity by showing all DOF deflection phases for a specific mode shape.*

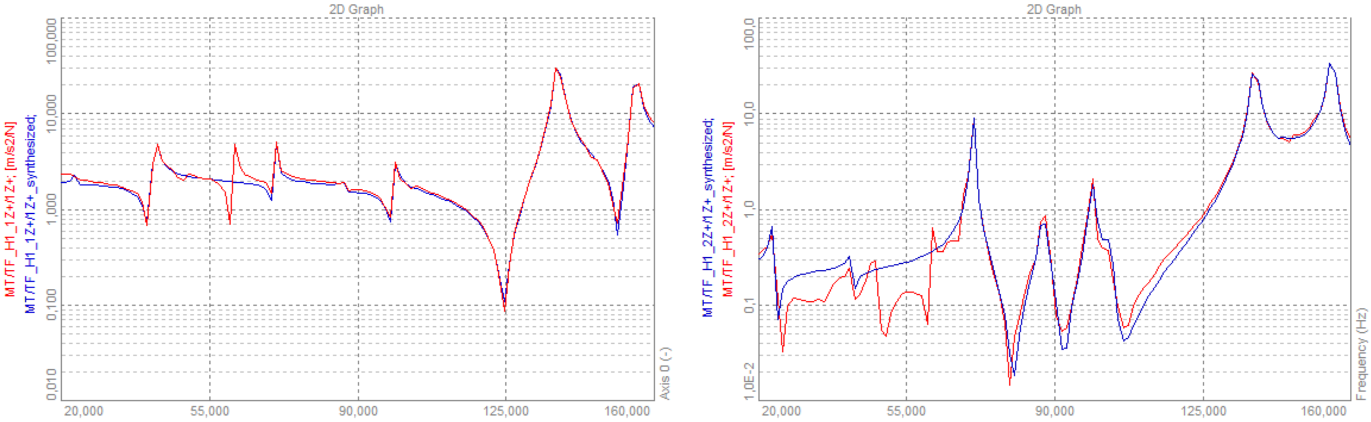
The complexity plot illustrates the phase of the individual DOFs compared to each other, which makes it possible to locate a specific DOF that might cause a high MCF.

For a mode having a low complexity, all DOFs are deflecting such that the mode shape can be described as a standing wave.

For a mode having a high complexity, some DOFs are deflecting such that the mode shape will contain parts that can be described as a traveling wave.

10.4 FRF synthesis

FRF Synthesis is used as a validation tool by comparing the FRFs from the estimated modal model (the synthesized FRFs) with the real measured FRF data. It is therefore possible to see how well the estimated model mimics the dynamics of the physical structure.



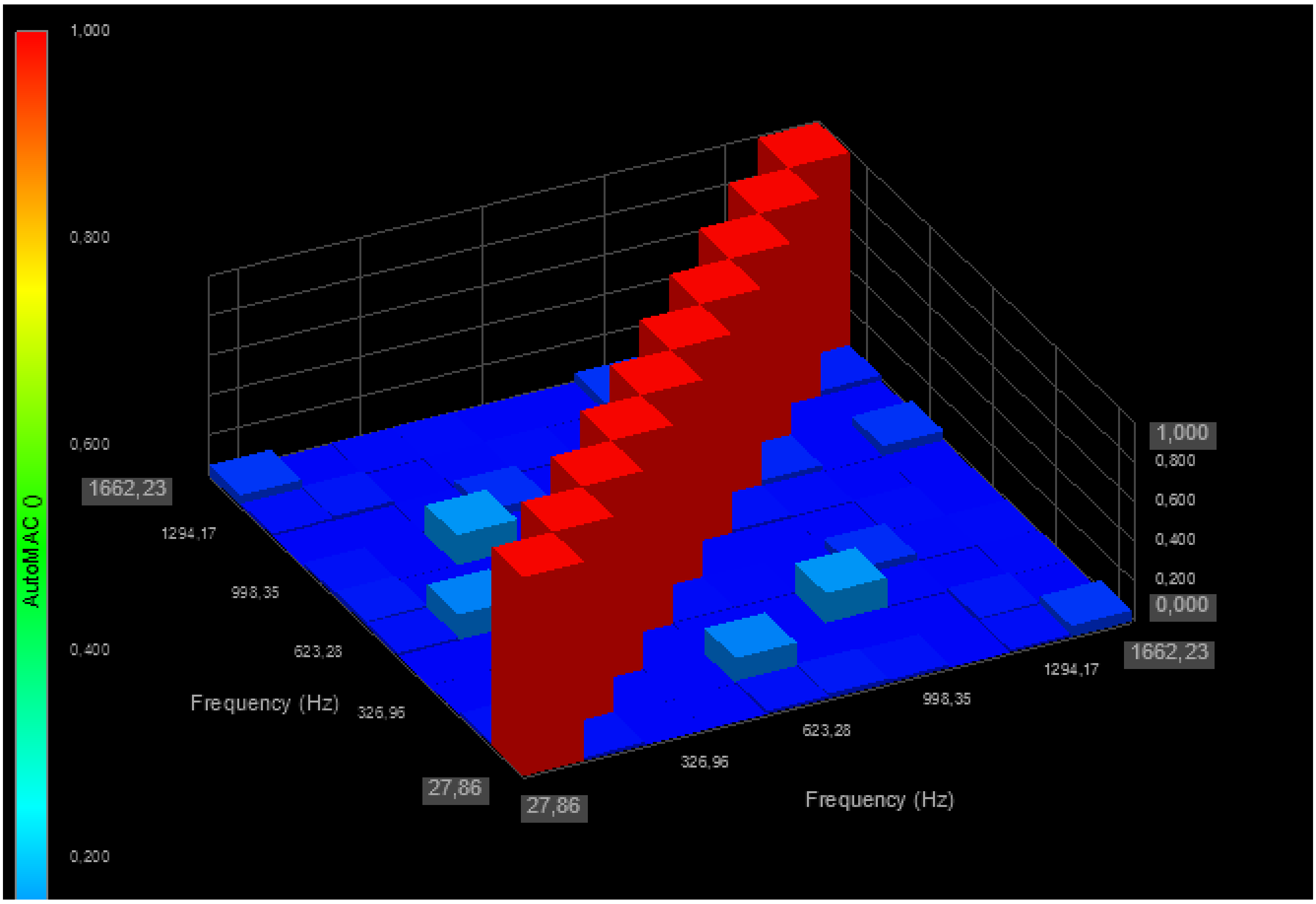
Example of synthesized FRFs (blue) and measured FRFs (red). Peaks found in the measured FRFs (red), but missing in the synthesized FRFs (blue) are modes which are not included in the estimated model. More modes can be included by adding more poles to the estimation on the Stabilization diagram.

10.5 AutoMAC

The Modal Assurance Criterion analysis (MAC) analysis is used to determine the similarity of two-mode shapes. The MAC number is defined as a scalar constant, between 0 and 1, expressing the degree of consistency between two mode shapes. In practice, any value between 0.9 and 1.0 is considered a good correlation. Below 0.7 is considered to indicate a bad correlation.

AutoMAC is a procedure that can be used to validate the accuracy of modal models. It is a measure of the similarity between estimated mode shape vectors from the same parameter estimation, same data set. All the diagonal values are 1 by definition, because each mode shape correlates perfectly with itself.

AutoMAC is a good tool for determining which and how many DOFs are required in the modal analysis to avoid spatial aliasing. With spatial aliasing, some modes look similar due to the insufficient number of DOFs used in the measurements. With insufficient DOFs used there will not be enough information to describe all modes separately. In an AutoMac plot, spatial aliasing will show high values at off-diagonal elements, indicating different modes look similar.



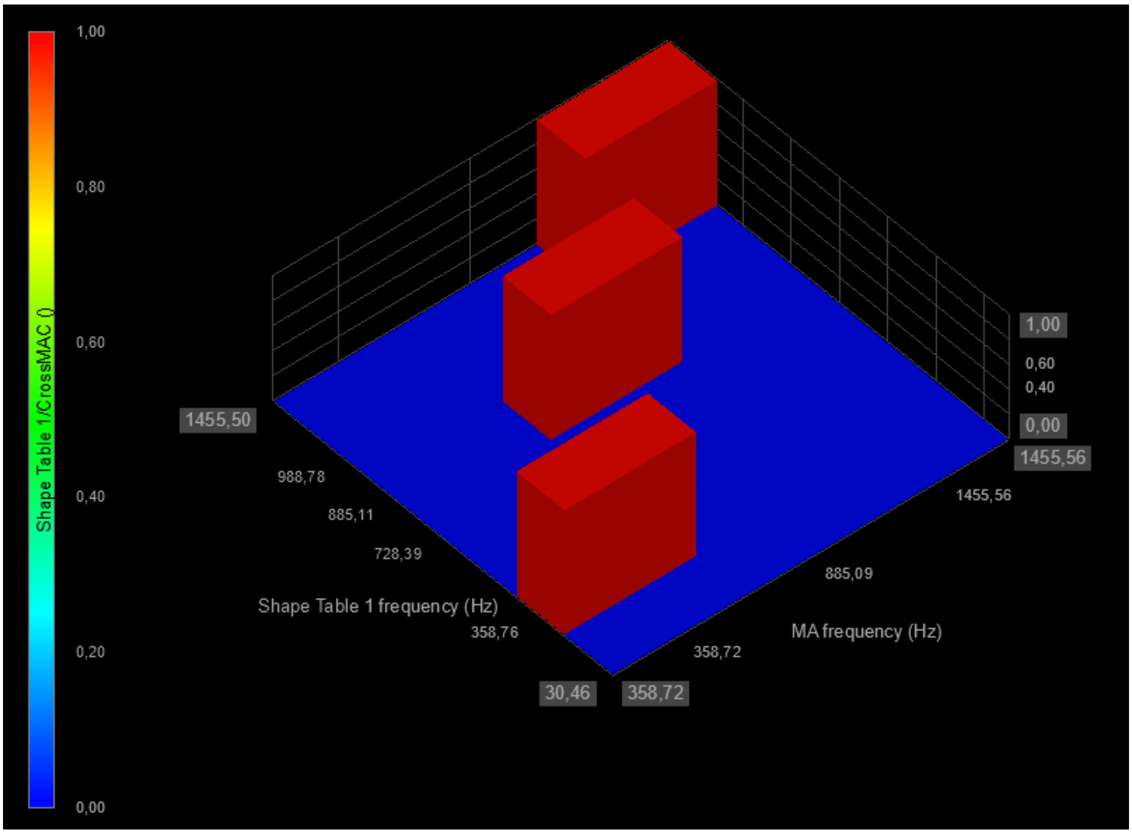
Example of an AutoMAC plot by using a 3D graph display widget. Ideally all off-diagonal cells should have relatively low values which indicates that all included modes are well separated into individual SDOF modes.

10.6 CrossMAC

Where AutoMAC is used to validate how well modes are uncorrelated between each other (from the same modal), CrossMAC is in the same way used to validate how well modes are uncorrelated but from different modal estimations.

With CrossMAC, modes from two different models are analyzed in order to see if the same modes from the two different estimates have good correlation, and to see if different modes from the different models have bad correlation.

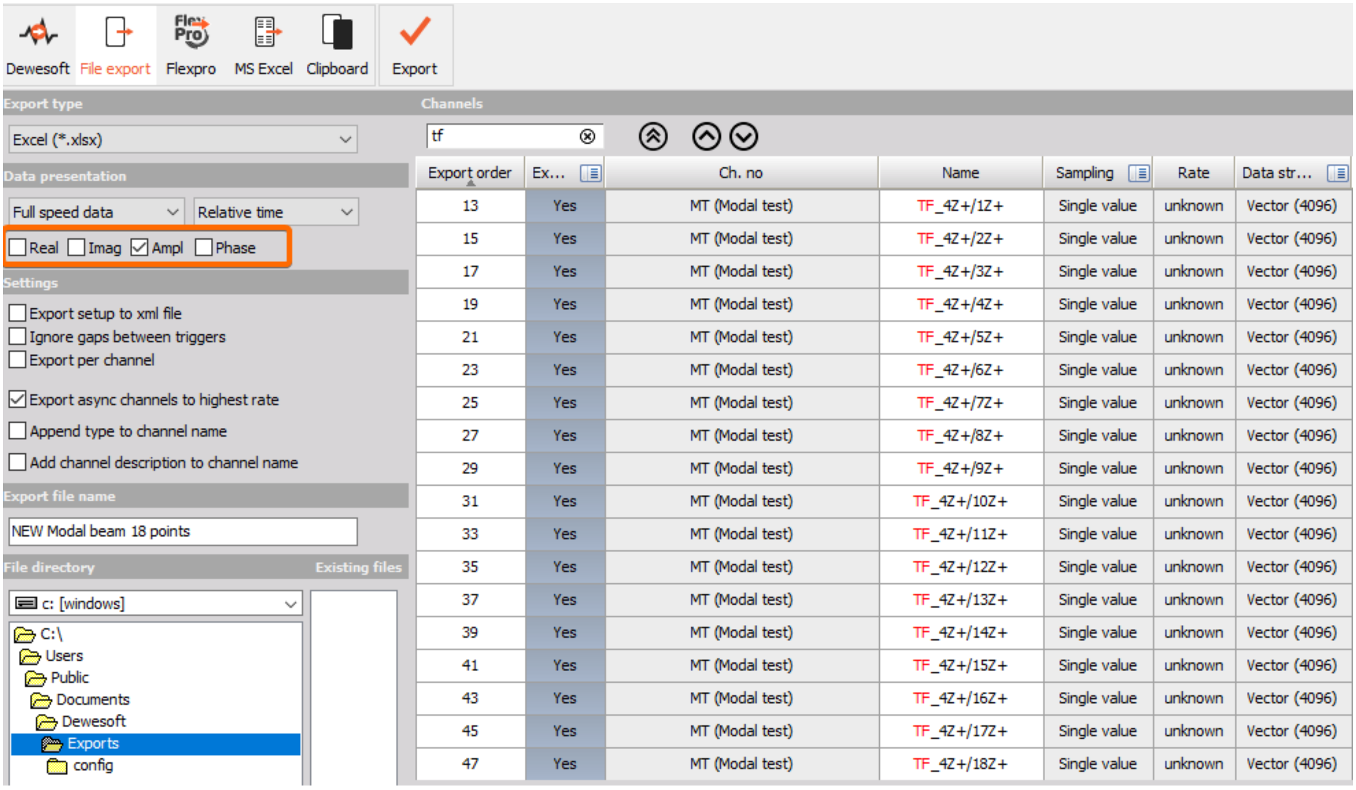
The two modals might contain different numbers of modes and therefore the CrossMAC does not necessarily have the same amount of modes on both axes as the AutoMAC always has.



Example of a CrossMAC plot by using a 3D graph display widget. Just like for the AutoMAC ideally modes should only correlate with itself and not the other modes. Hereby all CrossMAC values for a mix of different modes should have relatively low values. Having only relatively high values for CrossMac values at the crossings of the same modes indicate good correlation between the two different estimated modal models.

11. Export of data

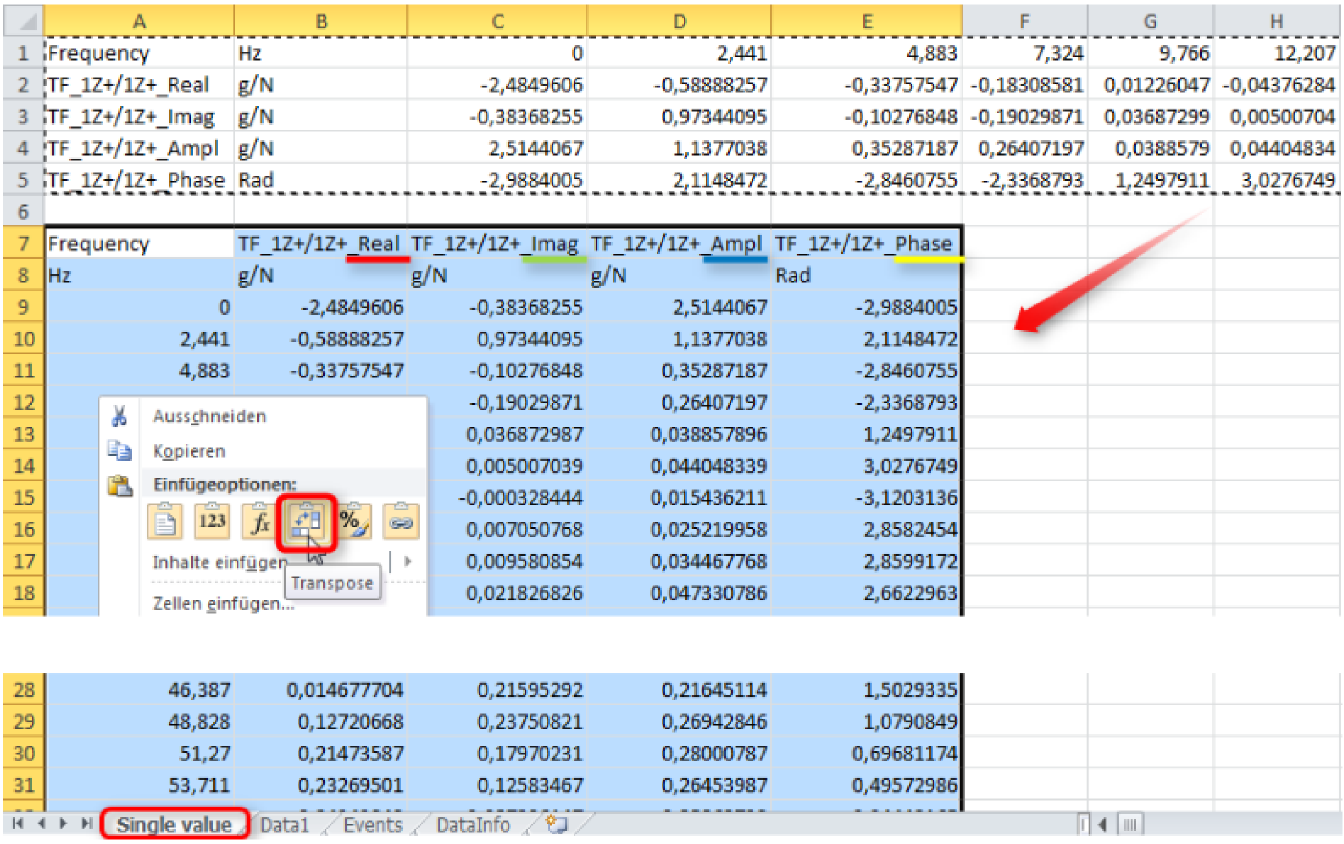
After the measurement is done the data can be exported to a lot of different file formats, e.g. UNV/UFF, Diadem, Matlab, Excel, Text... The transfer functions can be separately exported by Real, Imag, Ampl or Phase part, whatever you prefer.



In Analyze mode under Export the modal results can be exported to multiple data formats (Export). In the Channels table export settings can be defined for each channel individually.

In MS Excel for example the transfer function data will appear on a sheet called "Single value". For each transfer function Real/Imag/Ampl/Phase is exported.

If you prefer it differently, data rows and columns can simply be exchanged in MS Excel by copying and using the "Transpose" function from the submenu when pasting, as illustrated below:.



MS Excel exported Modal data rows are transposed in MS Excel to columns.

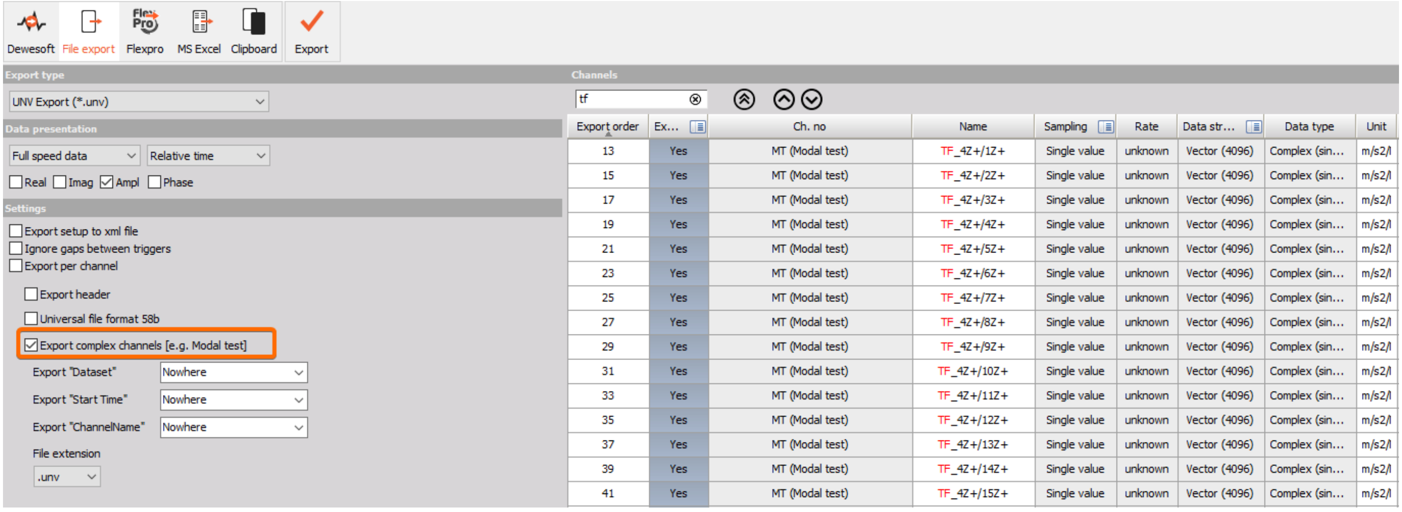
11.1 Export in UNV / UFF format

The Universal File Format (also known as UFF or UNV format) is very common in modal analysis. Depending on the header it can contain either transfer functions, coherence, geometry, ... or various other data.

The following example shows how to export data recorded by DEWESoft into Vibrant Technologies ME Scope analysis software and how to display it there.

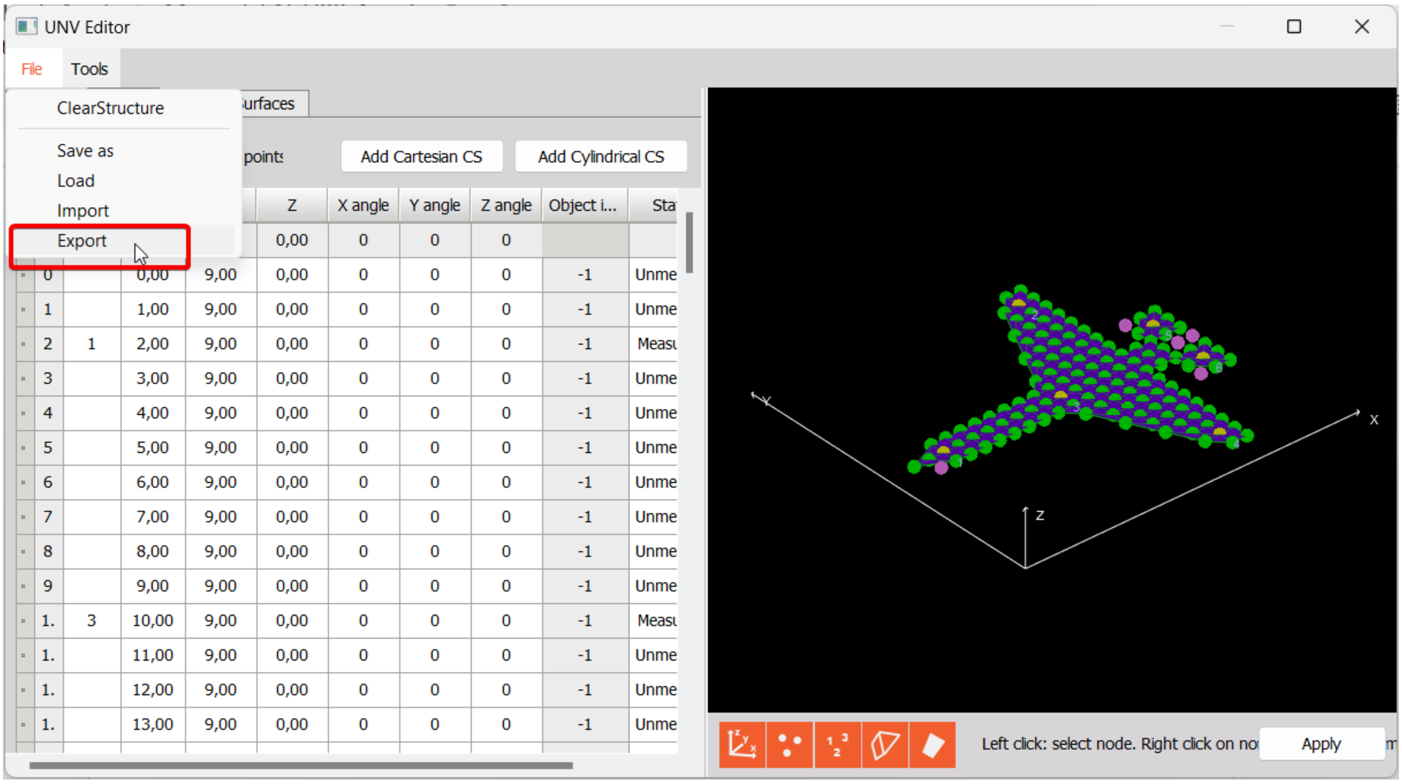
1. First choose the "Universal file format" from the export section and select all your transfer functions (you can use the Filter and type "TF" for simplification).

   It does not matter if you select Real/Imag/Ampl/Phase part, as the UFF/UNV export follows the standard. This will create a UNV datafile.



UNV export of FRF functions. The parameter 'Export complex channels' must be enabled.

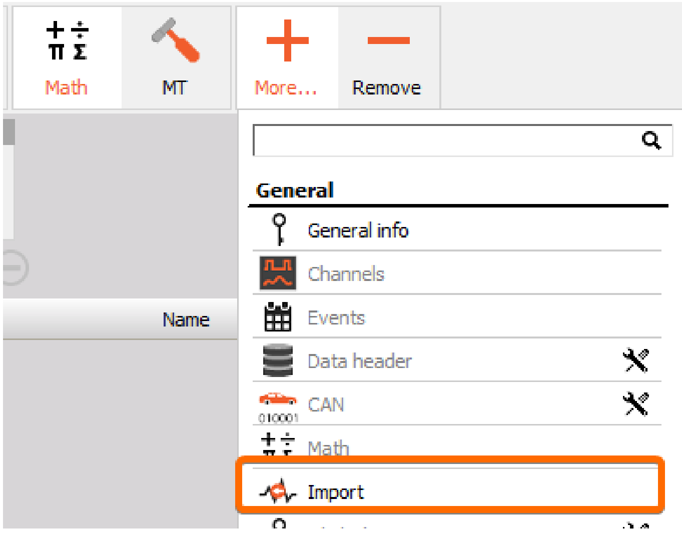
2. In the Modal geometry editor click on Export to save the structure also in the UNV data format.



Exporting the geometry to a UNV file.

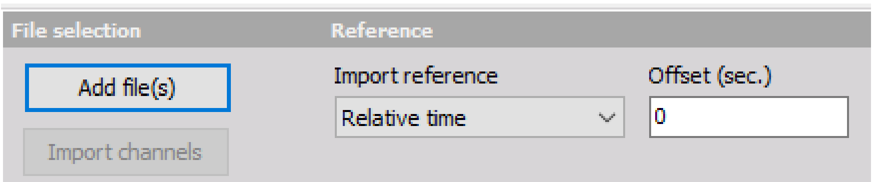
12. Merging multiple datafiles

If a modal test of a structure cannot be performed at once, the datafiles can be merged into a single datafile for easier identification of mode shapes, animation, etc.
Open one of the datafiles and go to the Import section.



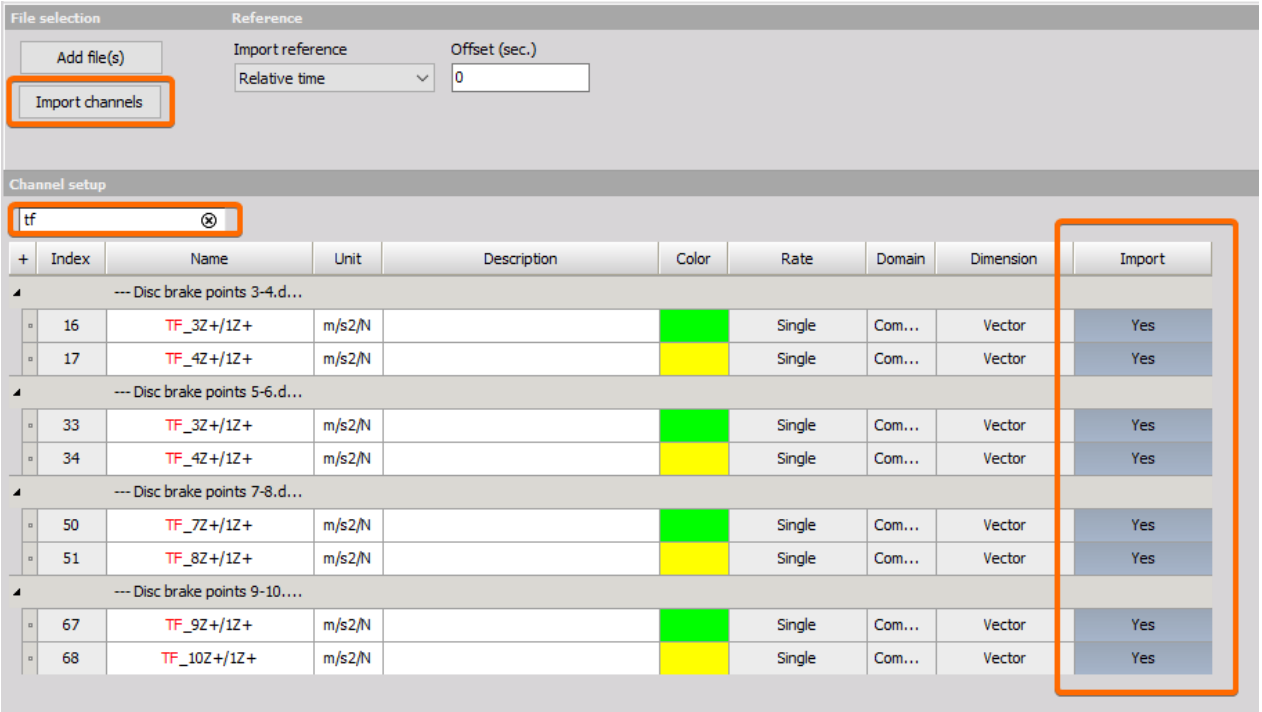
Add the Import module to the setup in order to merge FRF functions from other datafiles to the current datafile.

Add the datafiles that contain the transfer functions that you want to import.



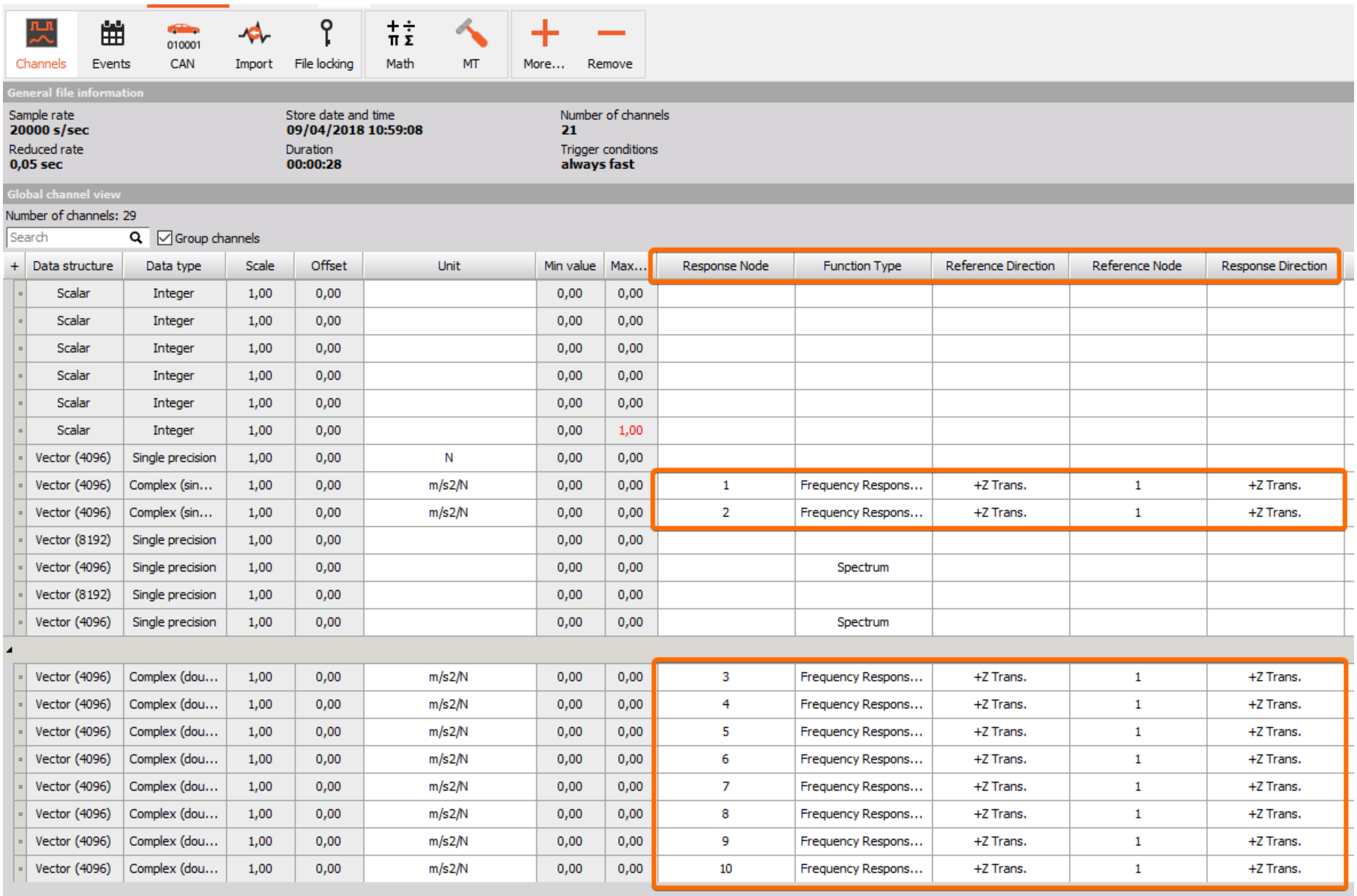
In the Import module select the datafiles containing FRF functions to import, by pressing 'Add file(s)'.

We only need to import single value vectors (FRF functions) and not the whole time history. Search for the FRF transfer functions, set import to Yes and click the Import button.



FRF transfer functions are found and selected to be imported. Hereafter, press 'Import channels'.

All the imported transfer functions have information about response- node and direction, function type, and reference- node and direction. If needed, then these parameters can be manually changed under the Channels section to match the actual modal test configuration.



Data structure	Data type	Scale	Offset	Unit	Min value	Max...	Response Node	Function Type	Reference Direction	Reference Node	Response Direction
Scalar	Integer	1,00	0,00		0,00	0,00					
Scalar	Integer	1,00	0,00		0,00	0,00					
Scalar	Integer	1,00	0,00		0,00	0,00					
Scalar	Integer	1,00	0,00		0,00	0,00					
Scalar	Integer	1,00	0,00		0,00	0,00					
Scalar	Integer	1,00	0,00		0,00	1,00					
Vector (4096)	Single precision	1,00	0,00	N	0,00	0,00					
Vector (4096)	Complex (sin...	1,00	0,00	m/s2/N	0,00	0,00	1	Frequency Respons...	+Z Trans.	1	+Z Trans.
Vector (4096)	Complex (sin...	1,00	0,00	m/s2/N	0,00	0,00	2	Frequency Respons...	+Z Trans.	1	+Z Trans.
Vector (8192)	Single precision	1,00	0,00		0,00	0,00					
Vector (4096)	Single precision	1,00	0,00		0,00	0,00		Spectrum			
Vector (8192)	Single precision	1,00	0,00		0,00	0,00					
Vector (4096)	Single precision	1,00	0,00		0,00	0,00		Spectrum			
Vector (4096)	Complex (dou...	1,00	0,00	m/s2/N	0,00	0,00	3	Frequency Respons...	+Z Trans.	1	+Z Trans.
Vector (4096)	Complex (dou...	1,00	0,00	m/s2/N	0,00	0,00	4	Frequency Respons...	+Z Trans.	1	+Z Trans.
Vector (4096)	Complex (dou...	1,00	0,00	m/s2/N	0,00	0,00	5	Frequency Respons...	+Z Trans.	1	+Z Trans.
Vector (4096)	Complex (dou...	1,00	0,00	m/s2/N	0,00	0,00	6	Frequency Respons...	+Z Trans.	1	+Z Trans.
Vector (4096)	Complex (dou...	1,00	0,00	m/s2/N	0,00	0,00	7	Frequency Respons...	+Z Trans.	1	+Z Trans.
Vector (4096)	Complex (dou...	1,00	0,00	m/s2/N	0,00	0,00	8	Frequency Respons...	+Z Trans.	1	+Z Trans.
Vector (4096)	Complex (dou...	1,00	0,00	m/s2/N	0,00	0,00	9	Frequency Respons...	+Z Trans.	1	+Z Trans.
Vector (4096)	Complex (dou...	1,00	0,00	m/s2/N	0,00	0,00	10	Frequency Respons...	+Z Trans.	1	+Z Trans.

*After importing FRF functions from other datafiles, then go to the **Channels tab** and verify that all FRFs have the **correct DOF** information. If you can't see the channels tap it can be added under '+ More'. If you do not find the DOF related columns in the Channels table, these columns can be added by right-clicking on the column header and selecting **'Edit Columns'**.*

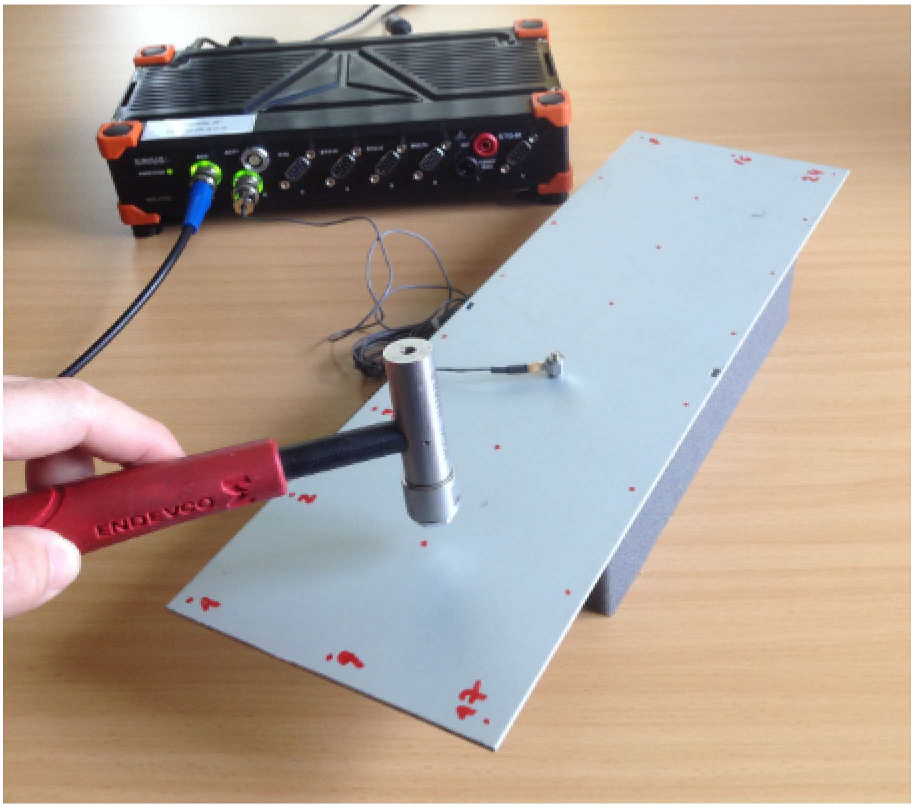
After the DOF parameters have been corrected for all actual and imported FRF functions, then they can be analyzed together as one big measurement.
For lighter analysis this can be done by using the Modal test SDOF Modal Circle widget and looking at the animated deflection shapes.
For full analysis this can be done by using the Modal analysis MDOF model estimation and looking at the animated mode shapes.

13. Examples (step-by-step)

13.1 Impact hammer (roving hammer)

Let's say we want to analyze this metal sheet structure. At first we define the direction of analysis (orientation up/down, Z axis), then we put it on a soft rubber foam that it can vibrate freely. Of course hanging it with rubber bands from the roof would be better, but would also take more time to wait at each point until the ringing fades out; for now we are fine with it.

Then mark equidistant points, in our case from #1 to #24. The higher the number of points, the more detailed the animation will be. It is also helpful to write numbers next to the points. They should be consistent on the structure, in the channel setup and in Modal geometry.

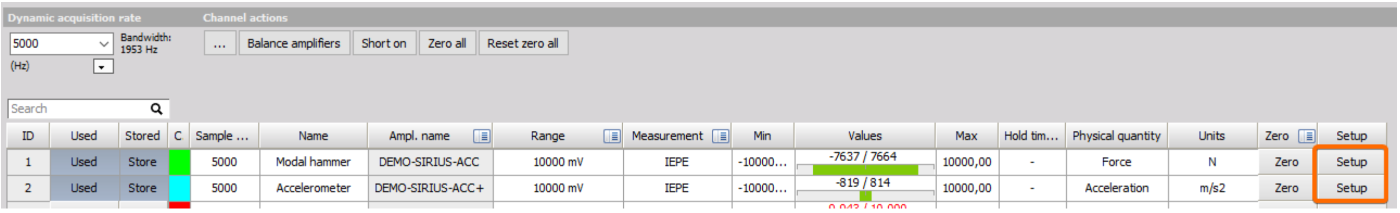


Example of a roving Impact hammer SISO test demonstration. The Reference response DOF is located at an non-ideal center location, where some modes will have a nodal (not moving) point. A better driving point location to mount the reference response would have been in one of the corners.

The hammer will move through the points, so in one point an accelerometer has to be mounted. In this case point #12 is selected as the reference response DOF.

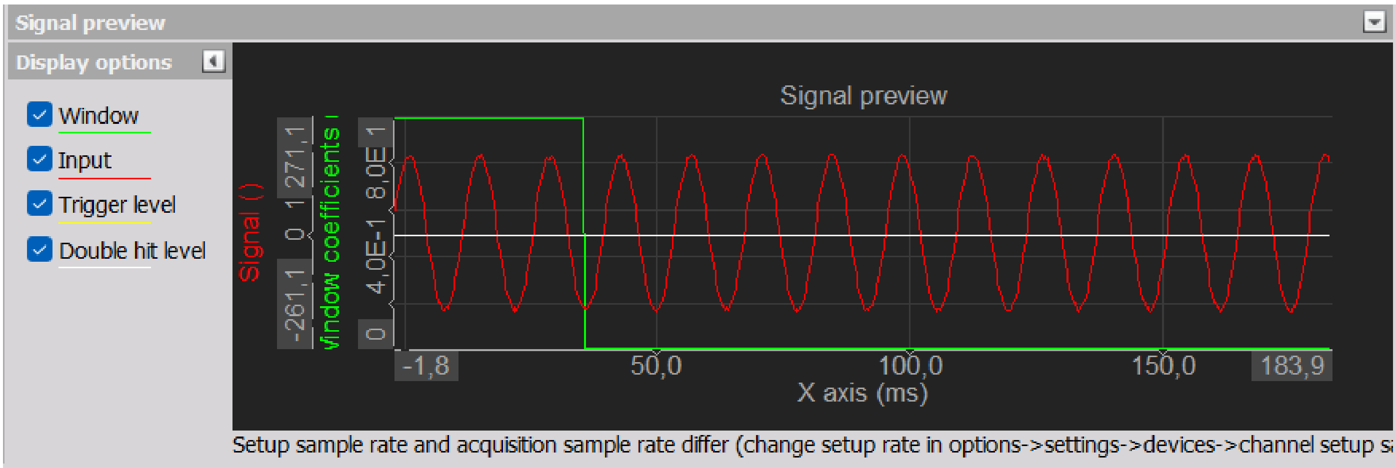
In order to acquire information for more resonance frequencies (modes), the reference response location should instead have been one of the corner DOF locations.

1. We define the sampling rate with 5000 Hz. Name the Modal hammer and accelerometer in the channel setup and apply the scaling. In our case both are of IEPE type, hammer is measuring force in N, accelerometer acceleration in g. Then go into the channel setup of the hammer.



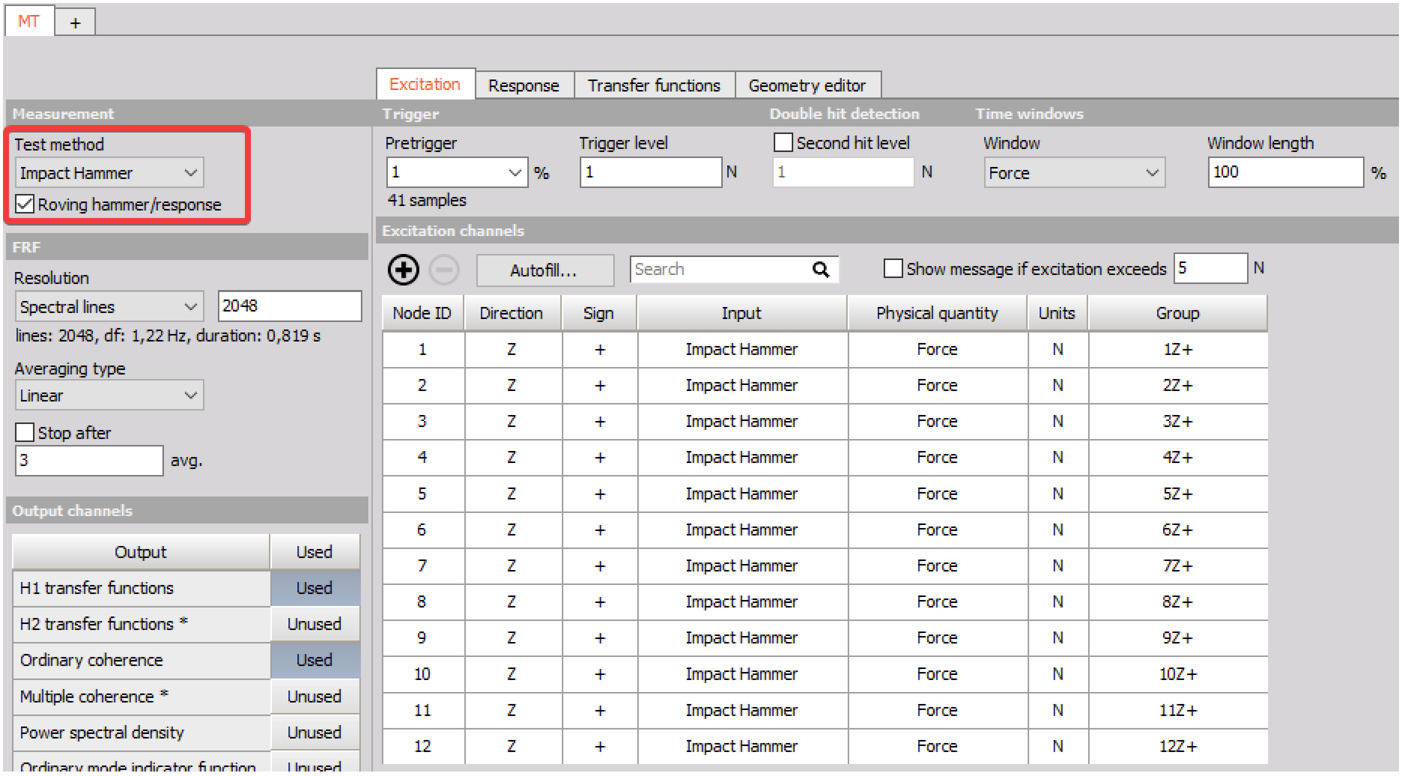
Configuring one impact hammer and one accelerometer under the Analog Input tab.

2. In the Modal test setup, choose the Impact hammer method, and use the “Roving hammer/response” option.
Do a test impact with the hammer on the structure. In the Signal preview, inspect the signals and their max value.

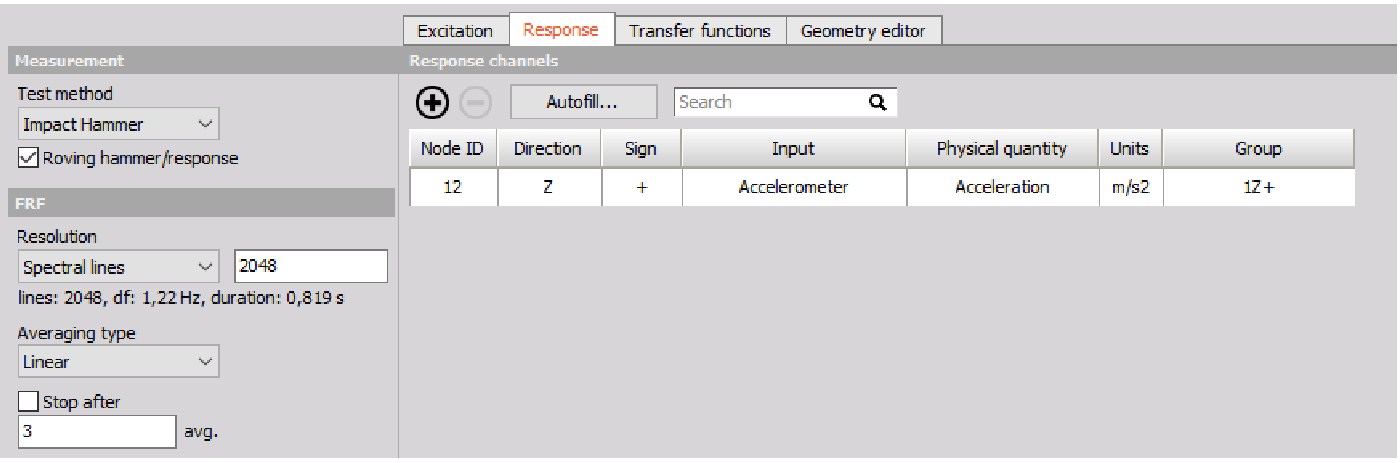


Example of the Signal preview section under the Modal test setup. Proper settings for the Trigger level and for the Second hit level can be determined from the Signal preview, by hitting with the hammer and inspecting the measured signal levels.

3. The trigger level should be set somewhere below the max value shown in the Signal preview. We will do 3 hits in each point, which are then averaged. The FFT window size is 2048, which gives a good line resolution of 1.22 Hz.

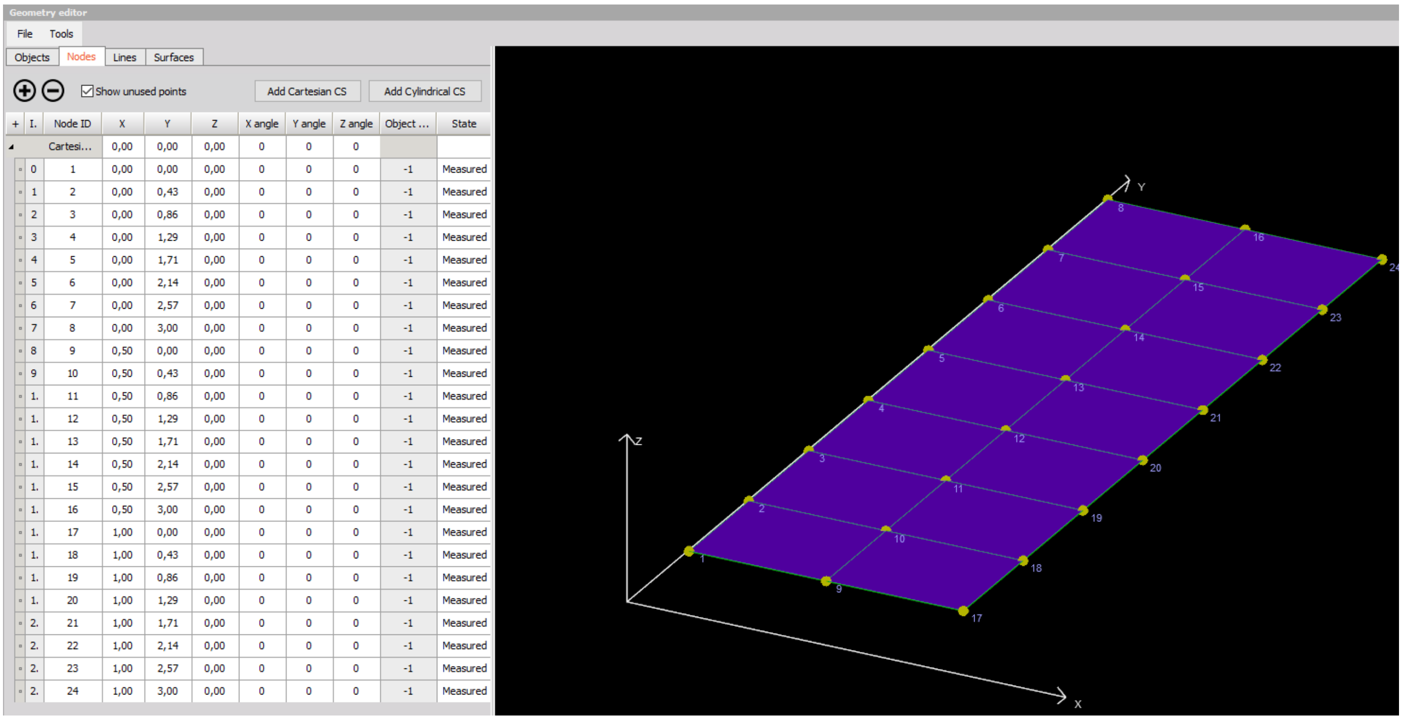


Test method set to Impact hammer. The Excitation table has rows of DOFs for all measurements where the hammer changes position or orientation. 3 averages (3 hits) per DOF ID is chosen, together with 2048 frequency lines in the output spectral results.



The Response table has only a single DOF row since that DOF is used for all measurements, as the reference response DOF.

4. Now that the points are defined, it is time for drawing the structure. In the MT setup go to the Geometry editor tab. Under Nodes add 24 points and their coordinates. You can draw trace lines between them and finally surfaces between them. This can also all be done automatically by selecting one of thepre-defined Objects.
For this example take care that the excitation direction Z is upright and should have the same level for all points of this structure.



I.	Node ID	X	Y	Z	X angle	Y angle	Z angle	Object ...	State
	Cartesi...	0,00	0,00	0,00	0	0	0		
0	1	0,00	0,00	0,00	0	0	0	-1	Measured
1	2	0,00	0,43	0,00	0	0	0	-1	Measured
2	3	0,00	0,86	0,00	0	0	0	-1	Measured
3	4	0,00	1,29	0,00	0	0	0	-1	Measured
4	5	0,00	1,71	0,00	0	0	0	-1	Measured
5	6	0,00	2,14	0,00	0	0	0	-1	Measured
6	7	0,00	2,57	0,00	0	0	0	-1	Measured
7	8	0,00	3,00	0,00	0	0	0	-1	Measured
8	9	0,50	0,00	0,00	0	0	0	-1	Measured
9	10	0,50	0,43	0,00	0	0	0	-1	Measured
1.	11	0,50	0,86	0,00	0	0	0	-1	Measured
1.	12	0,50	1,29	0,00	0	0	0	-1	Measured
1.	13	0,50	1,71	0,00	0	0	0	-1	Measured
1.	14	0,50	2,14	0,00	0	0	0	-1	Measured
1.	15	0,50	2,57	0,00	0	0	0	-1	Measured
1.	16	0,50	3,00	0,00	0	0	0	-1	Measured
1.	17	1,00	0,00	0,00	0	0	0	-1	Measured
1.	18	1,00	0,43	0,00	0	0	0	-1	Measured
1.	19	1,00	0,86	0,00	0	0	0	-1	Measured
1.	20	1,00	1,29	0,00	0	0	0	-1	Measured
2.	21	1,00	1,71	0,00	0	0	0	-1	Measured
2.	22	1,00	2,14	0,00	0	0	0	-1	Measured
2.	23	1,00	2,57	0,00	0	0	0	-1	Measured
2.	24	1,00	3,00	0,00	0	0	0	-1	Measured

Geometry editor which can be found either in the MT setup under Geometry editor, or by going to Measure mode and selecting Edit on the properties page for the Modal geometry widget.

5. After creating the geometry, you switch to measure mode, usually you should have an auto-generated screen called “MT: Impact hammer”. There the Modal geometry widget is already shown.
Now it's time for a test hit, and finalizing the display arrangement. In measure mode – without storing – you can do a test hit, to fill the displays with signals. Immediately the structure will be animated in the first point. If the auto-generated screen does not look like below, you might have to assign the channels to the instruments.

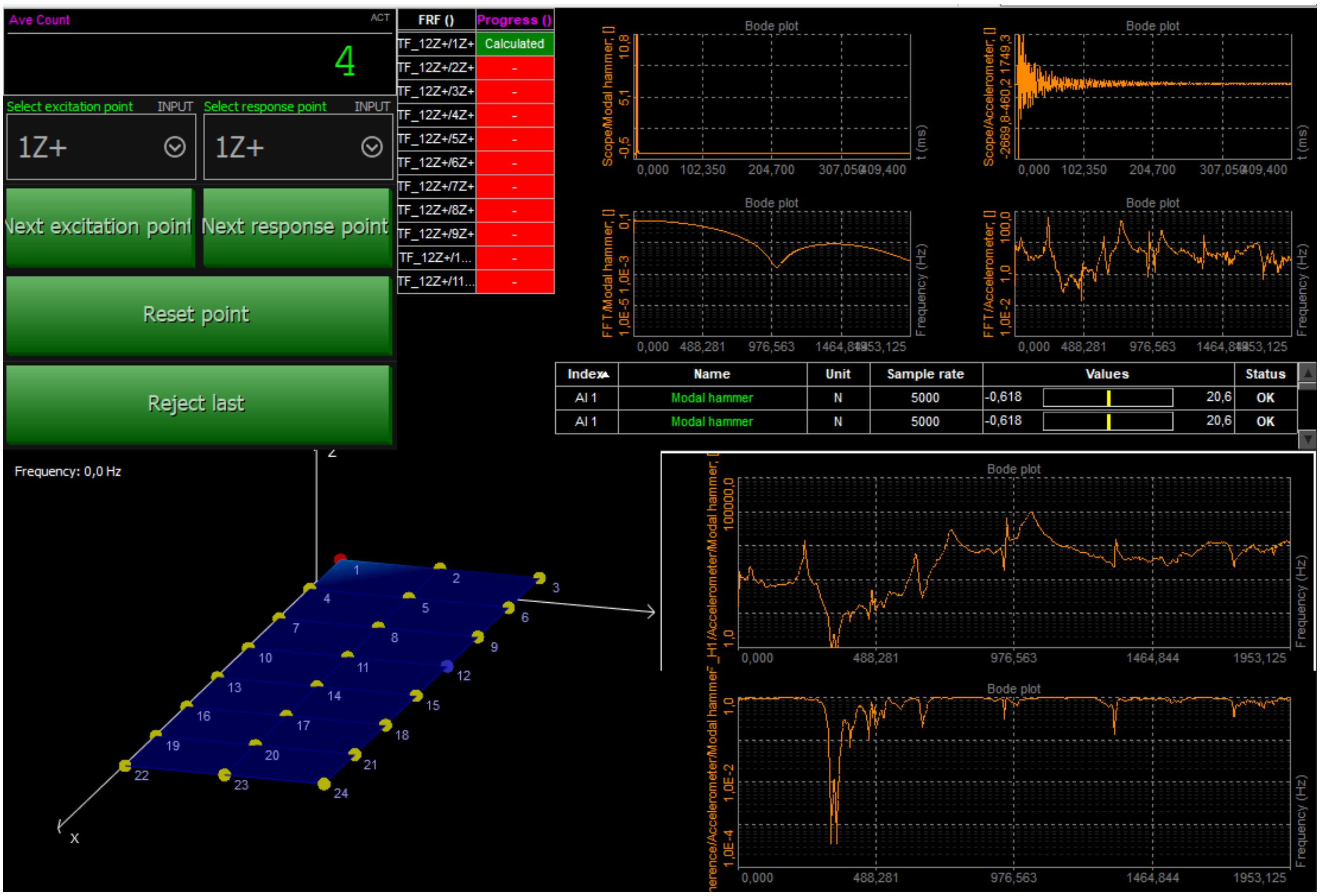
On the left side of the screen you have a control channel to navigate between the measured points, reset or reject points and with a drop-down menu manually switch between wanted points.

Right to the control channel is the progress table, where you can observe all the transfer functions that were defined in the modal test setup and if they were already measured or not.

On the top right corner you can see the time domain signal of excitation and response channels, below there is a frequency spectrum of excitation and response channels.

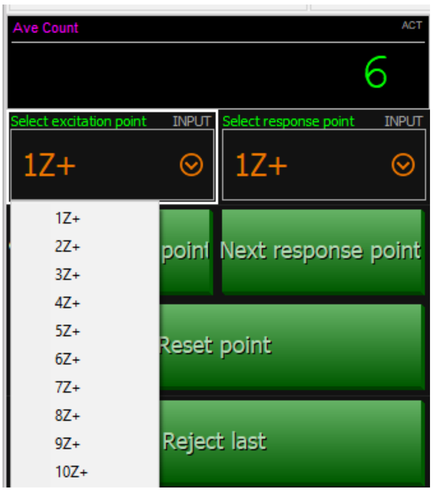
In the bottom left corner of the display is modal geometry, showing the animation of the structure at a certain frequency.

In the bottom right corner of the display, you can see the transfer function (amplitude, phase, real or imag) and coherence function.



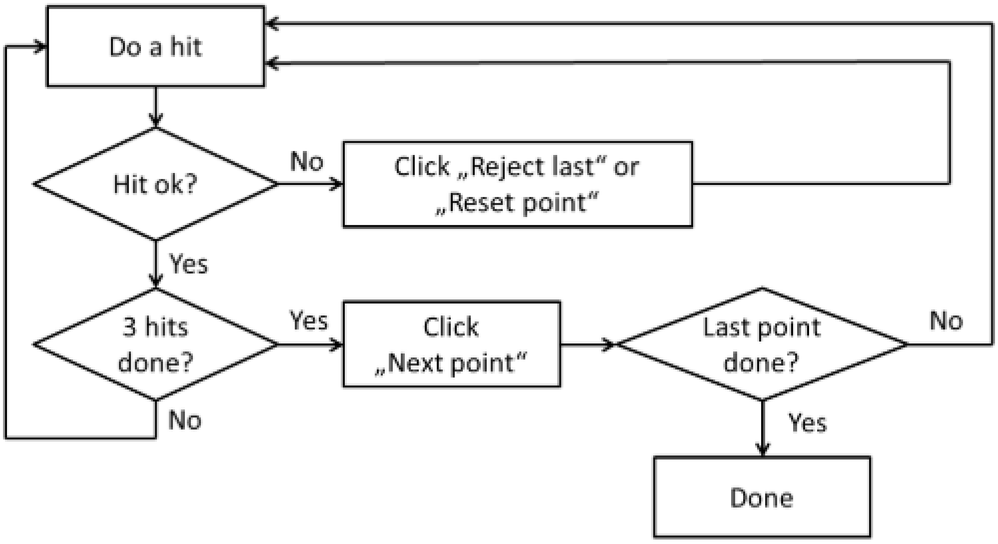
Measure mode pre-defined display layout for roving impact hammer testing.

6. Now we are ready for the measurement. Start storing and do 3 hits on point #1. The scope and FFT graphs will be updated after each hit, so you can visually check for double-hits or “bad” hits and reject them. If you hit a wrong point, you can also reset the whole point. After clicking the “Next point” button, the point number increases, always showing you the current transfer function (e.g. 12-1, 12-2, ...).
We can freely select input/output transfer pair, by dropdown, during the measurement routine



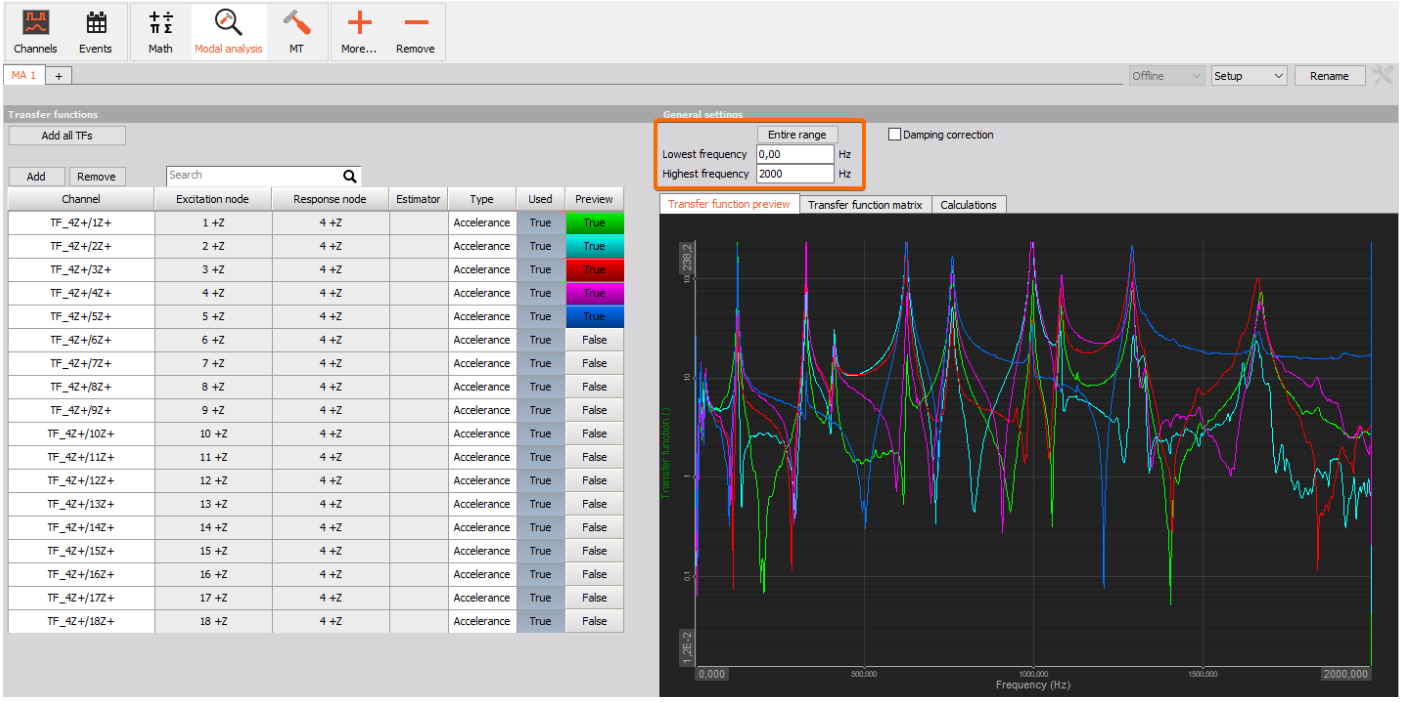
When roving the hammer remember to change the excitation DOF group.

The procedure can also be described by a flow chart:



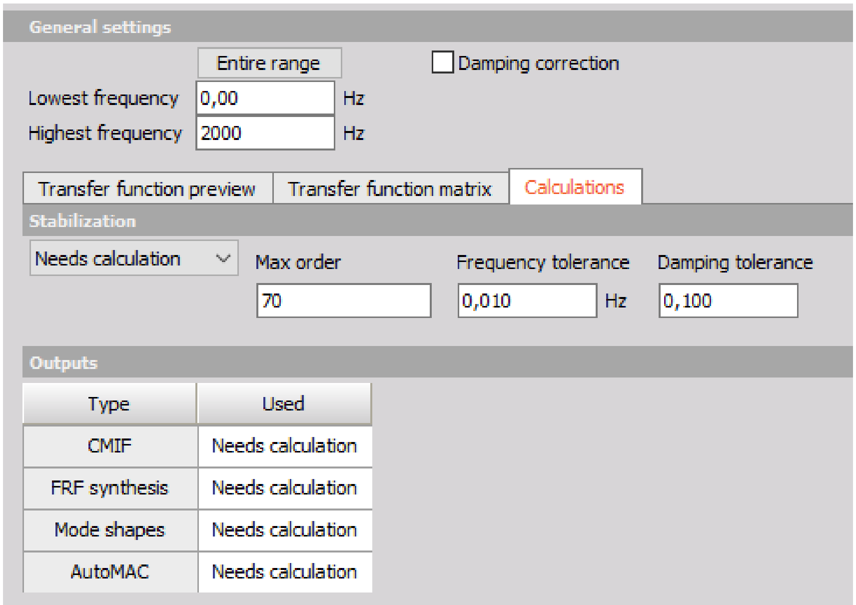
Workflow chart for roving Impact hammer modal testing.

7. When finished, go to Analyze mode. Automatically the last stored file is reloaded.
To make a further analysis of the modal test data, add the Modal analysis module. Add the transfer functions that were measured in the Modal test module. With the preview option you can determine the useful frequency range in which you want to make further analysis. In our example, we will set the frequency range from 0 Hz to 2000 Hz.



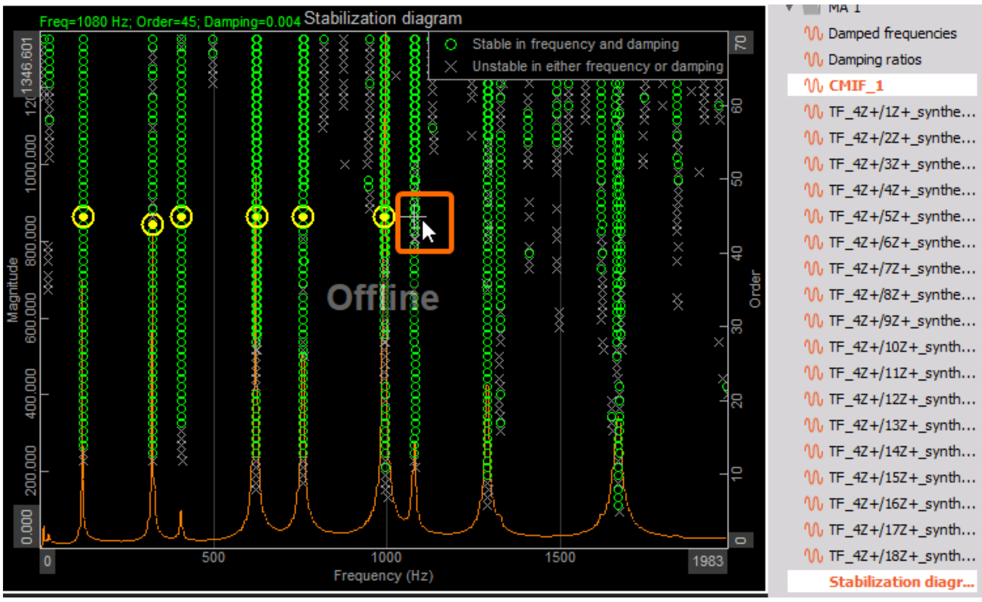
Modal analysis setup screen: measured FRF functions have been added from Modal test, and the transfer function preview display is used to determine the frequency range of interest for further analysis.

Modal analysis uses the LSCF algorithm to calculate the stable poles. In addition, CMIF and Mode shapes are calculated and FRFs are synthesized.



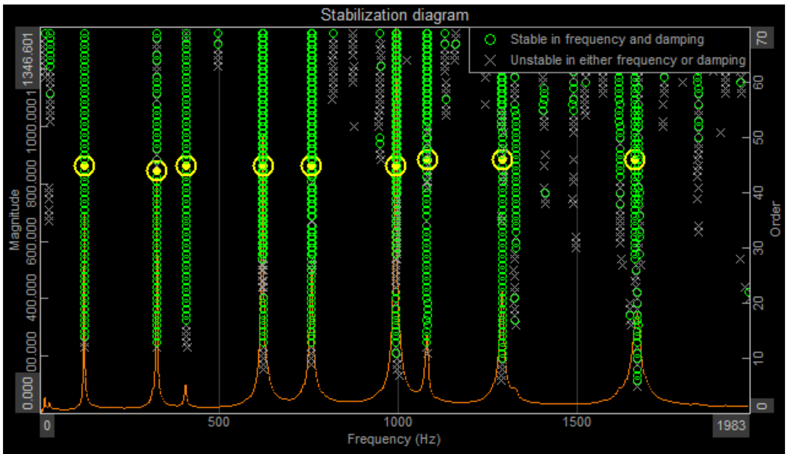
The Calculations tab in the Modal analysis module Setup. The frequency range is set between 0 Hz and 2 kHz. Frequency and Damping tolerances are set for when to indicate a stable pole for a mode. Outputs will be created after Recalculation under Review Mode.

The results are shown on a widget called stabilization diagram. Click on the stable poles that you want to further examine.



Poles are selected for relevant modes. Modes are indicated by the orange CMIF curve. Poles should be selected where multiple poles are found stable. After adding or removing poles, the modal estimation needs to be recalculated. Until Recalculate is done the modal results will be set to Offline.

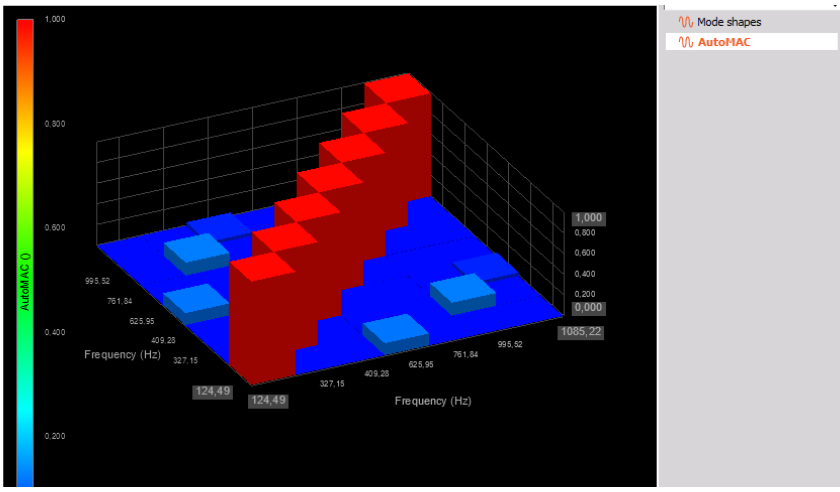
The results can be displayed in a 2D table, where we can see the frequencies of mode shapes and damping ratios of modes.



Mode (Id)	Damped frequencies (Hz)	Damping ratios (%)
1	124,50	0,489
2	327,10	0,208
3	409,33	0,626
4	625,89	0,172
5	757,93	0,651
6	995,09	0,375
7	1084,62	0,134
8	1291,34	0,399
9	1663,44	0,558

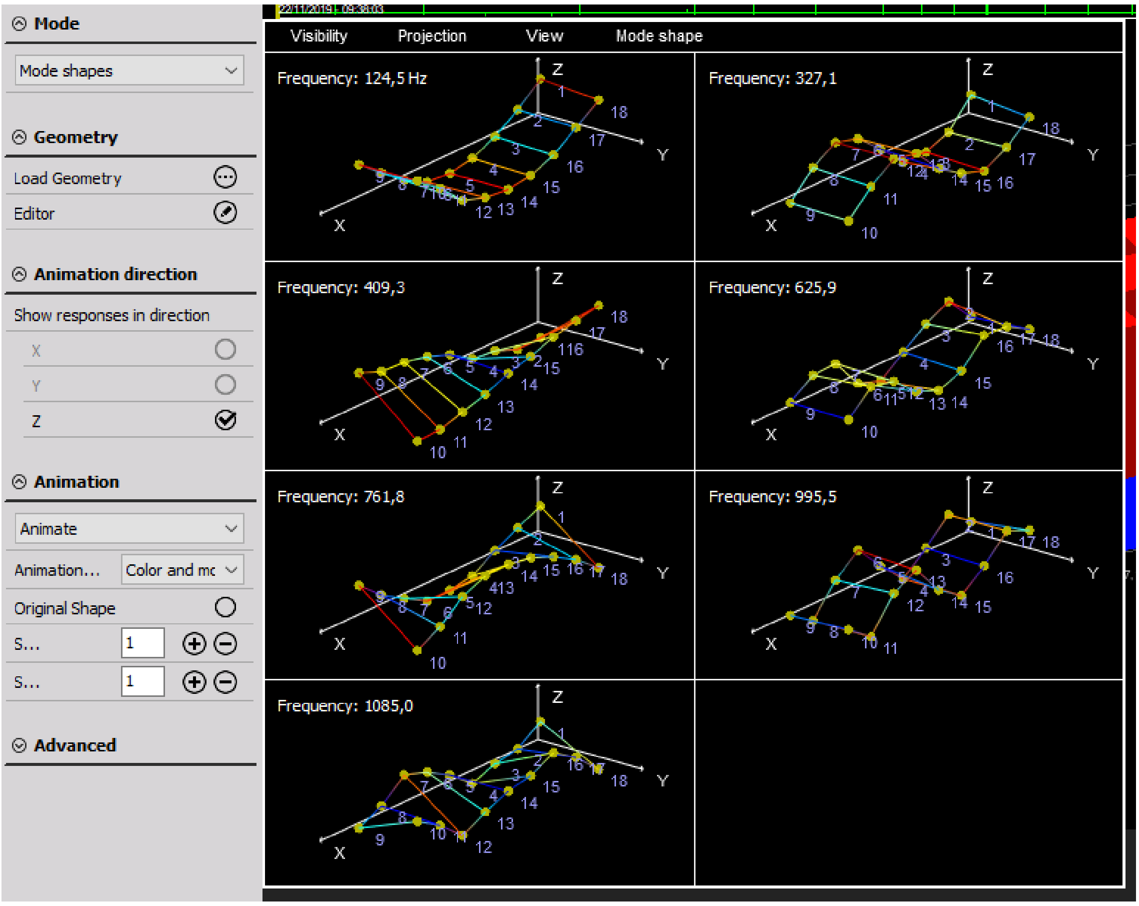
After Recalculation the modal parameters are estimated in accordance with the selected poles.

To show the similarities between mode shapes we display the AutoMAC matrix on a 3D graph.



The AutoMac is visualized using a 3D Graph widget, and shows well estimated and separated SDOF modes.

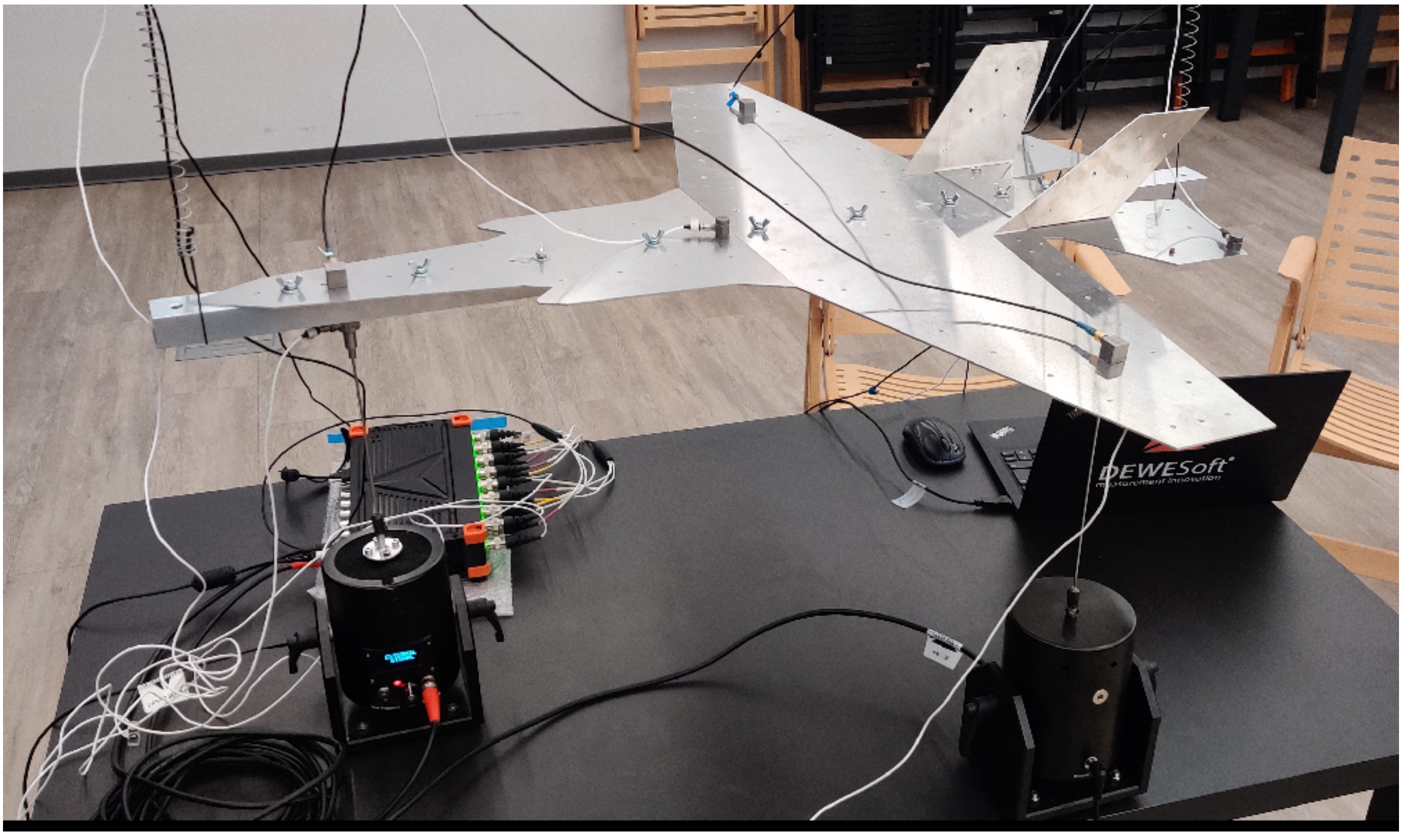
To show the animation of mode shapes we click on the modal geometry and select Mode shapes as the animation mode.



All estimated mode shapes can be visualized with the Modal geometry widget.

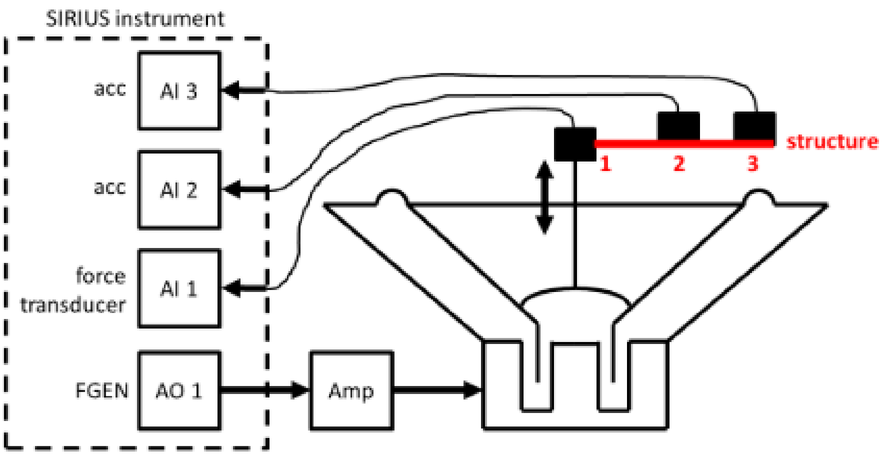
13.2 MIMO measurement example with 2 shakers

This is a practical example showing measurement of structural properties of a demo airplane, excited with 2 shakers.



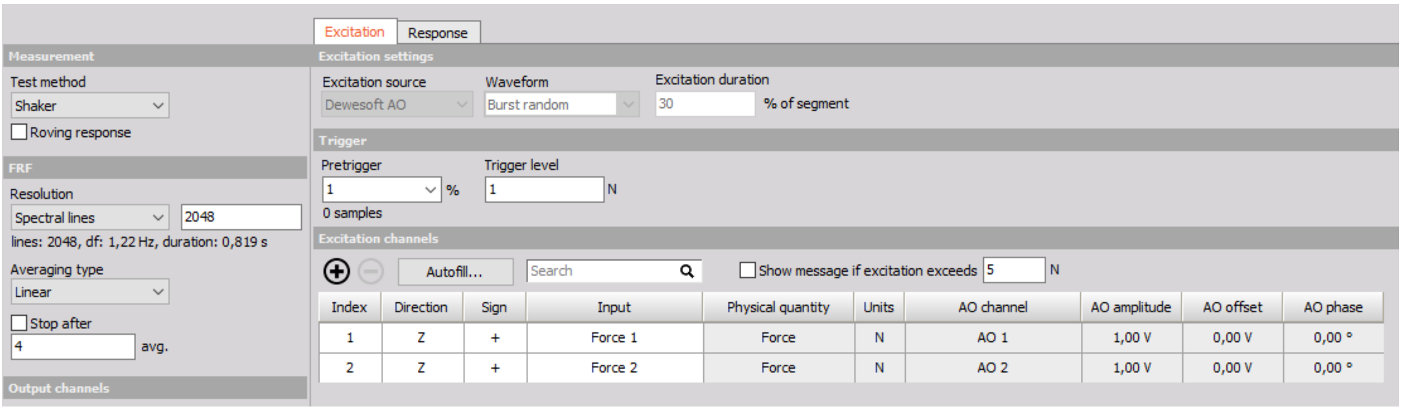
MIMO shaker modal test configuration. Two shakers are mounted to the plane using steel stingers and force sensors. 6 accelerometers are mounted at spread locations which together will represent the dynamics of the structure the best.

The airplane was excited with 2 shakers. Between a stinger and a structure, the force transducer was mounted. The response of the structure was measured in 6 different locations.
The shakers were driven by Dewesoft's function generator.

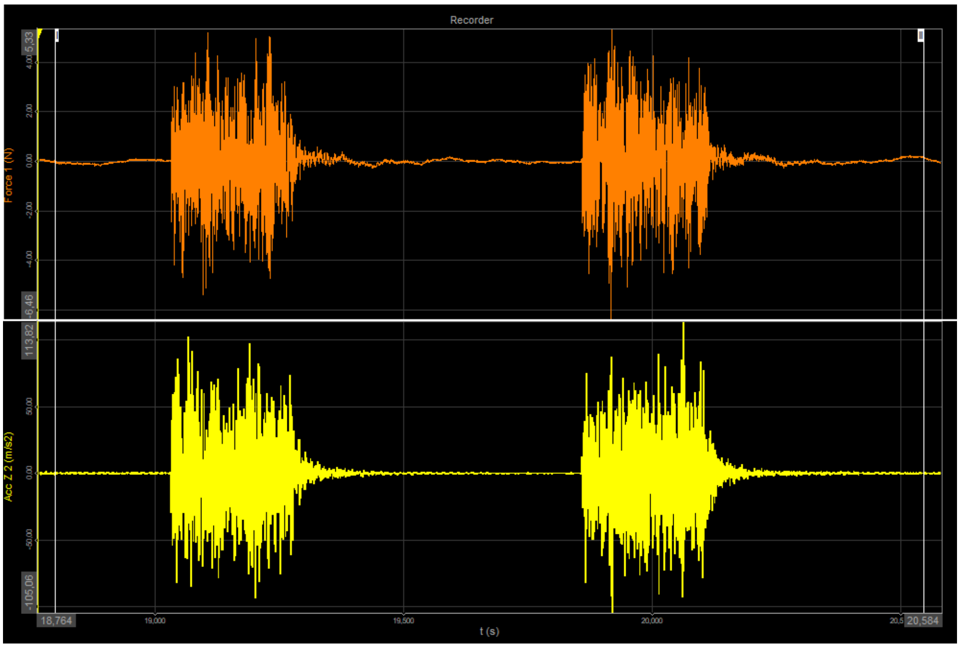


Sketch example of a DEWESoft SIRIUS DAQ device with 3 input channels and one output channel. Two inputs are used for response channels and one for an excitation channel. The output channel sends out the generated signal waveform for the shaker.

The airplane was excited with burst random excitation, where the shakers were exciting the structure for 30% of the block duration and the remaining 70% of the segment, the structure was vibrating freely.

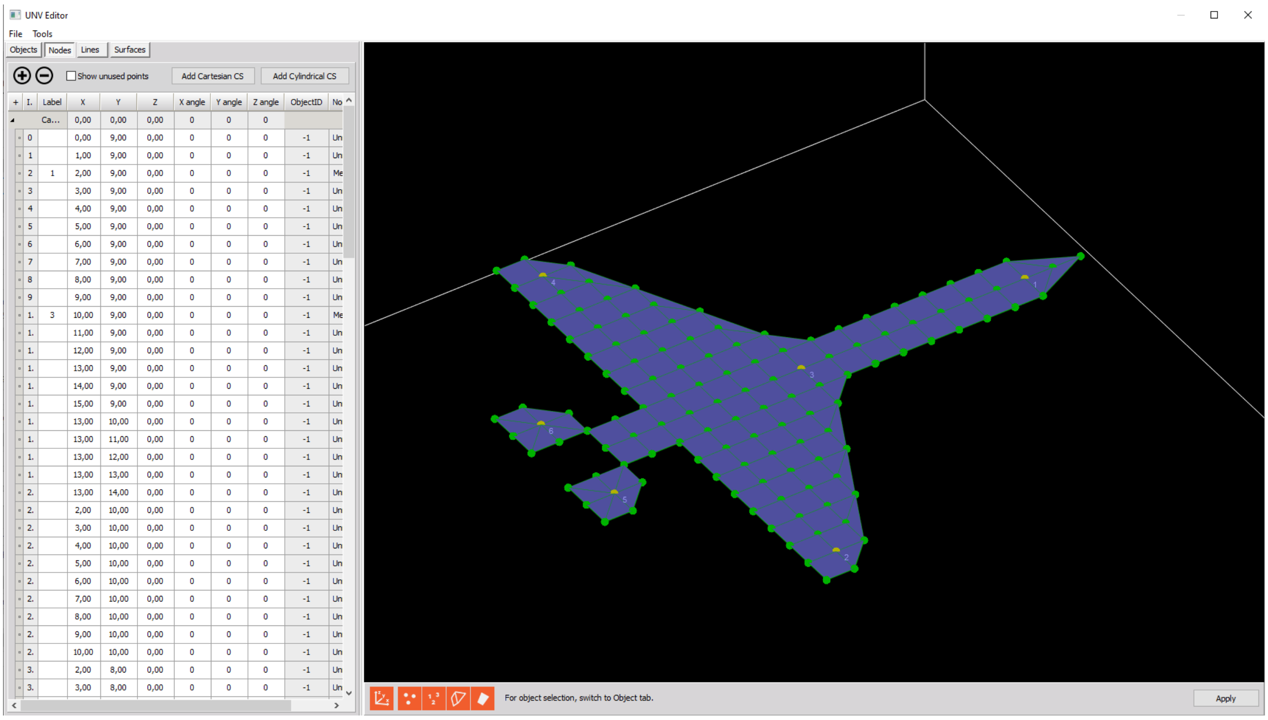


Burst random shaker test configuration, with 2 shakers using DEWESoft Analog Output channels. The Excitation duration of the bursts are set to 30 % of the time block duration (segment) used for each spectral measurement.



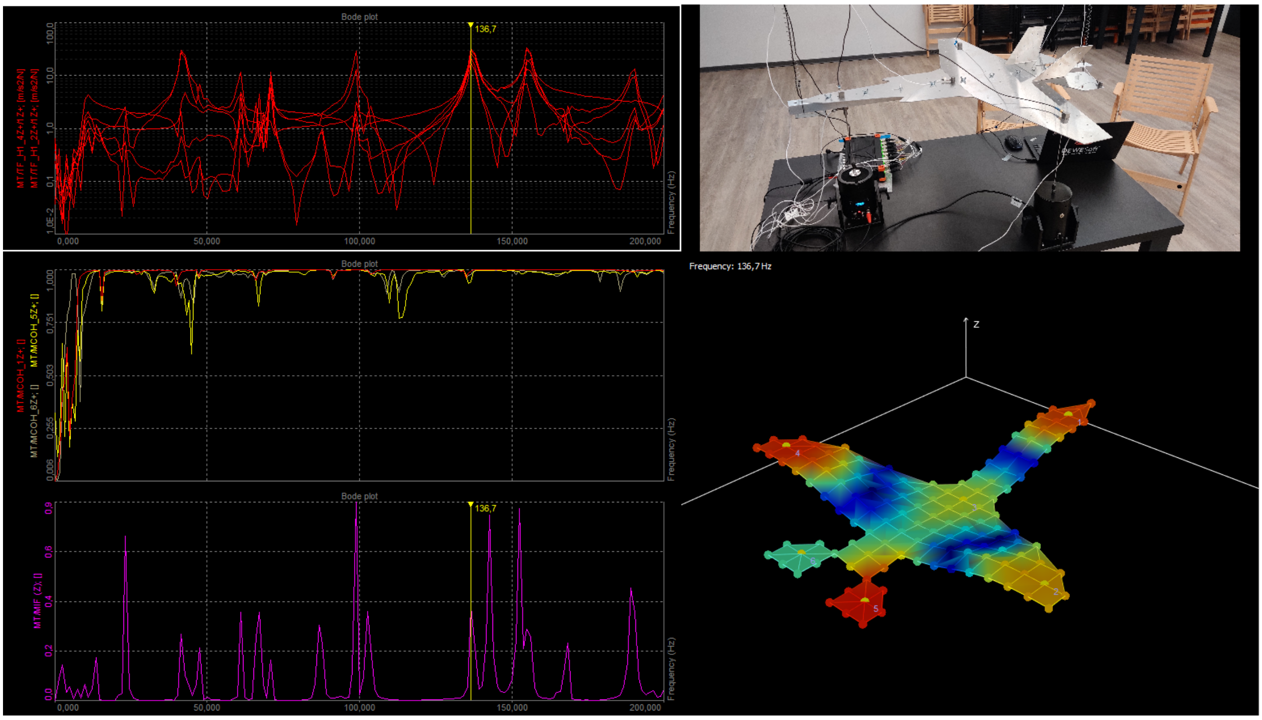
Burst random time waveforms visualized using a Recorder widget. The burst duration is controlled by the Excitation duration parameter.

Modal geometry editor was used to draw a model of an airplane. Only the points where we actually measured the response were selected as Measured, others were set as Unmeasured. If the unmeasured points are connected with measured points using tracelines, also the unmeasured points will be animated with interpolation between the points.



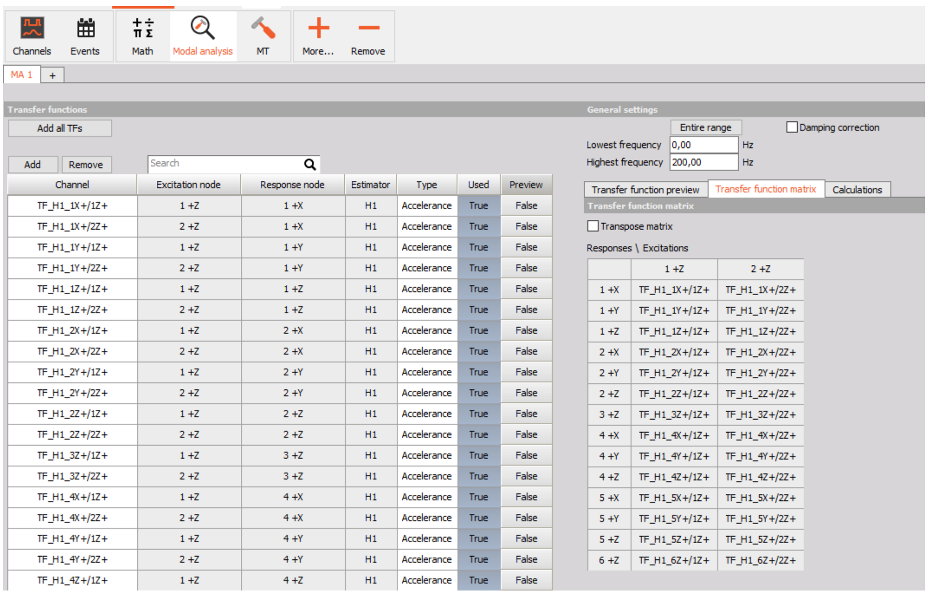
Settings for Measured and Unmeasured points are found under the Geometry editor. Unmeasured points will use interpolation between measured points for the deflection animation.

When we take a look at the results from the Modal test module, we can see the TFs, coherences and MIF. The structure can be animated at the resonance frequencies.



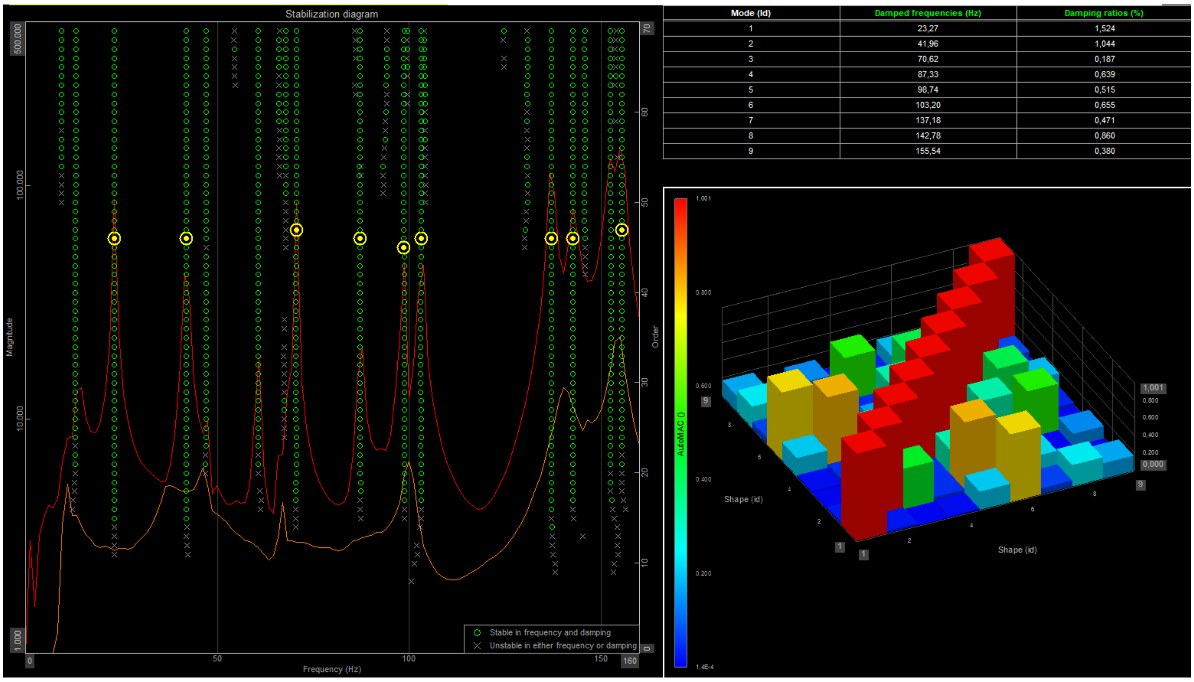
Results from the MIMO shaker modal test.

Next step was to add a Modal analysis module where all the TFs from the Modal test were taken as an input channel. We defined the frequency range from 0 Hz to 200 Hz. The damping correction is not needed because we didn't have an exponential window on response channels.



In the Modal analysis setup the frequency range to analyze further is set to from 0 Hz to 200 Hz.

Stable poles are displayed on the Stabilization diagram where we selected the first 9 modes. On the right side we also checked the AutoMAC matrix to see the similarity between the modes.



Results from the MIMO shaker modal analysis

14. Time ODS

ODS (Operational Deflection Shape) and hereunder Time ODS testing can be a valuable tool for inspecting critical structural deflections on operating structures, since for operating structures it can be difficult to do proper experimental modal testing, with external applied forces.

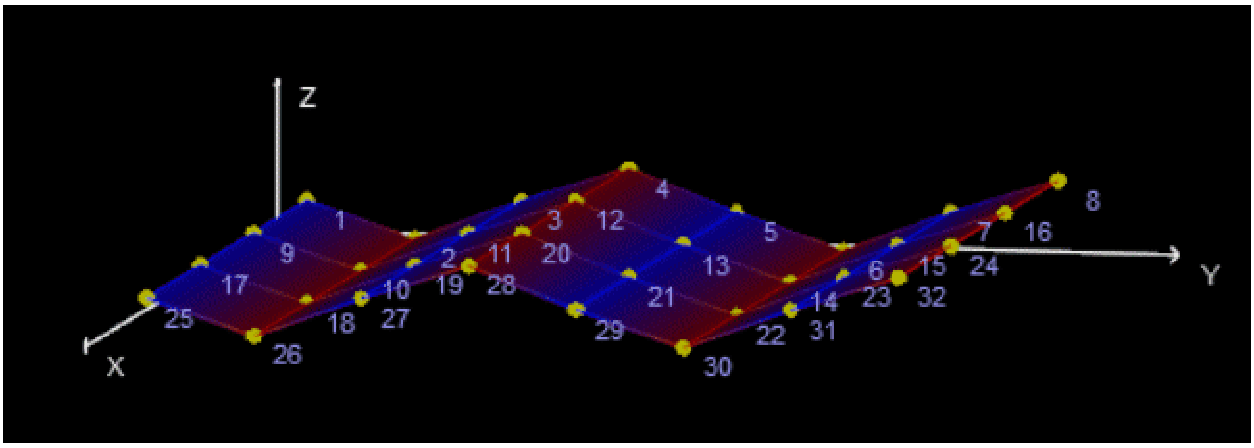
Examples of operational test conditions can be measurements of e.g. continuous signals from running engines, or transient signals from earthquakes, explosions, drop-tests, and many more operational test scenarios.

Time ODS is used to animate and visualize structural deflections based on measured time data. With Time ODS the user can adjust the time for where to look at deflections on geometry animations.

The geometry animations can show the structural deflections both in real-time and when performing post-analysis. In post analysis the playback speed can be reduced and hereby deflection patterns can be properly evaluated.

Time ODS do only use response channel time data - no excitation channels, and no reference is required. Geometries can be created or imported in the Geometry Editor and the DOF nodes will be mapped to the processed response channels via the Time ODS Response channels table.

The Time ODS plugin supports deflection animation in the physical quantities acceleration, velocity and displacement.



Example of Time ODS animation of a plate measured at 32 response nodes

Important:
All Input channels must have the same physical quantity, which has to be either: Displacement, Velocity or Acceleration.

Normally Time ODS is performed when enough response sensors are available to cover the DUT (Device Under Test) without roving.

14.1 How to use Time ODS

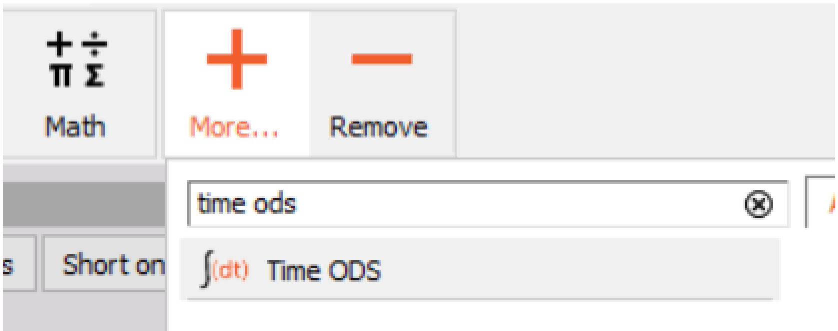
14.1.1 Mount response sensors

When using Dewesoft Time ODS a sufficient amount of response sensors are mounted on the operating DUT to gather the desired deflection characteristics with each measurement. Response sensors can e.g. be accelerometers.

The response sensors are typically mounted at locations that will reveal relatively large deflections, locations of great importance or at weak spots which are relevant for inspection.

14.1.2 Setup configuration

In the Dewesoft software application Time ODS can be added (in the Ch. setup tab) as a plugin to the current setup by selecting it from the Plugin list, as shown below:



The Time ODS plugin can be added to the setup through the plugin list.

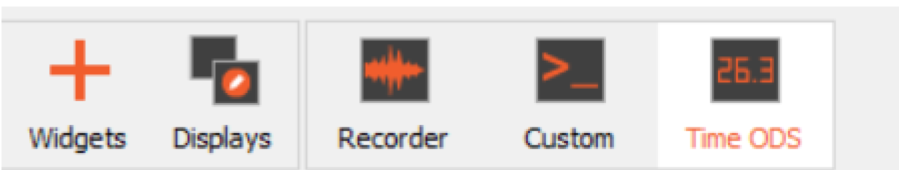
Through the Time ODS plugin:

- Input response sensors are selected to be used
- DOF information is added to the Inputs
- Output physical quantity and unit scaling is selected.

All adjustable parameters are described in more detail in the section 14.2 Plugin parameters.
Online help for the individual Time ODS parameters can also be found by pressing “F1” while focussing on Dewesoft Time ODS plugin.

14.1.3 Measurement

After configuring the Time ODS channel setup, going to the Measure screen will now indicate a Time ODS display template:



After Time ODS has been added to the setup, a related display template will be available when proceeding to Measure.

The default Time ODS display template contains a time Recorder widget showing the selected group of channels processed by the Time ODS plugin. The template also contains a geometry widget which is used to set up and animate the structural deflections.

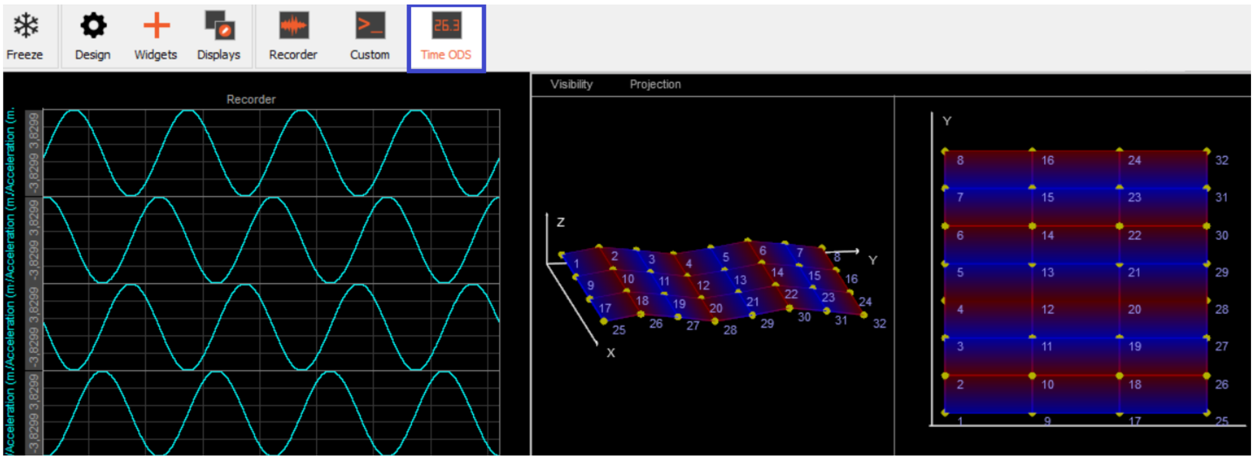


Illustration of the Time ODS display template, showing the deflection values over time together with the structural deflection animation.

Under the Measure screen it is possible to monitor the Time ODS live, and to perform data recording for storing, export, post-analysis and reporting.

14.1.4 Geometry configuration

In order to visualize the Time ODS a geometry has to be assigned to the geometry widget.
By selecting the geometry widget to be highlighted, then related widget properties become available on the right side of the screen.

Under the widget properties panel a pre-prepared geometry can be loaded, or the geometry Editor can be used to create a new one.

When configuring the geometry the Node IDs, defined for the response channels in the Time ODS Response channels setup table, must be selected for the related geometry DOF Node IDs. In this way the Time ODS output channels are linked to the correct geometry DOF nodes - enabling the geometry to be animated accordingly.

More detailed information on how to configure the geometry widget can be found in section 6.6 Modal geometry widget.

14.1.5 Post analysis

With recorded time data Time ODS post-analysis enables detailed inspection of the measured structural deflections, by letting the user manage how the recording should be replayed.

In Analyze mode after loading an acquired data file (.dxd file) the user will get the same channel setup and display setup as were used while doing the recording.

Under Review, by pressing the Play button the recording will begin to be replayed. To investigate deflection shapes of operating structures in more detail the playback speed can be adjusted by the user as illustrated below:

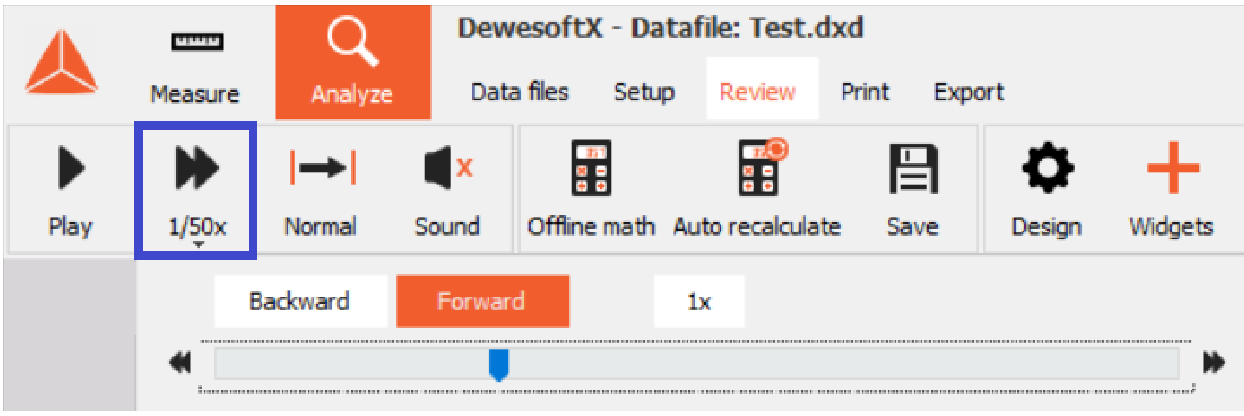
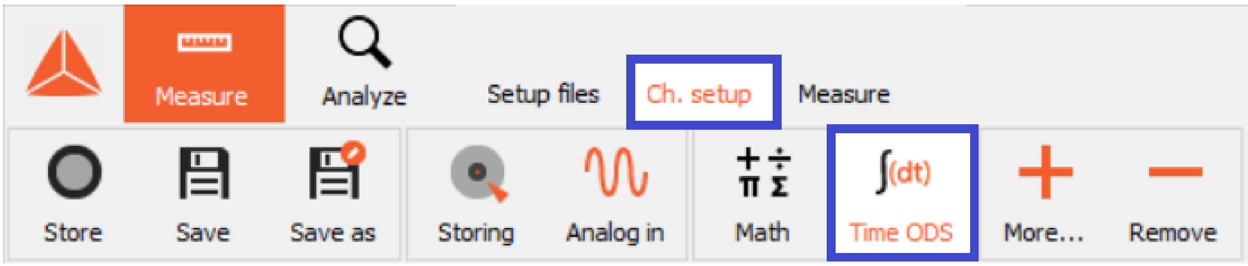


Illustration of how to adjust the playback speed and direction of a data file in Analyze mode.

More information about replaying data files can be found here -linking to the online manual for Replaying Data.

14.2 Plugin parameters

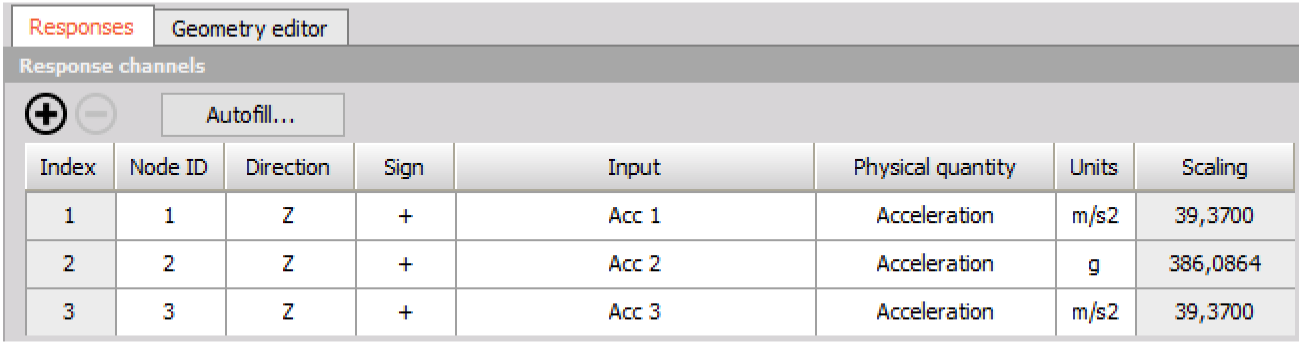
In this section all Time ODS plugin setup parameters will be described.



Time ODS plugin setup parameters are found under Ch. setup - Time ODS.

14.2.1 Response channels

The Response channels table defines and connects DOF information and Input response channels. DOF information defines node point locations and directions to measure. Such DOF information is added to the measured Input response channels enabling the response channels to be properly visualized on geometry animations.



Index	Node ID	Direction	Sign	Input	Physical quantity	Units	Scaling
1	1	Z	+	Acc 1	Acceleration	m/s2	39,3700
2	2	Z	+	Acc 2	Acceleration	g	386,0864
3	3	Z	+	Acc 3	Acceleration	m/s2	39,3700

Response channels are added for the Time ODS processing. DOF information, being Node ID, Direction, and Sign should be added as the sensors are mounted to the structure. The Node ID numbers will link to the Node IDs of the structural geometry.

Index
The Index column in the Response channels table is only used to help with overviewing the Response channels table, e.g. when having a large amount of channels. The numbering will start from 1 and increase up to the number of response channels added.

Node ID
The Node ID column refers to the DOF Node IDs - the number relating to the physical location of the selected Input response sensor. The Node IDs are also used when creating a geometry animation. Hereby the node points on a geometry and the response Node IDs are mapped together, such that geometry animations can reflect the measured characteristics. In the geometry the Node ID numbers can be configured under the Nodes tab.

Direction
The Direction defines in which directions (x, y, z) measurements were performed for related DOFs and Node IDs. The selected Directions are also used for geometry animations to reflect measured deflections in the correct directions.

Sign
The Sign defines the orientation (+, -) of the DOF for the specified Direction. The Sign should reflect orientation of the related response sensor.

Input
The Input determines which Input response channel that is related to the specified DOF information (Node ID, Direction and Sign).

Physical quantity
Indicates the Physical quantity of the Input response channel. Changes to the Physical quantity of Input response channels are global changes and will affect all usages of the related channels.
The Input Physical quantity has to be either Acceleration, Velocity or Displacement.
If the Physical quantity is different from either Acceleration, Velocity or Displacement, then the related table cell will indicate '<Custom>', and the related DOF point will not reflect the measurement on geometry animations.

Unit

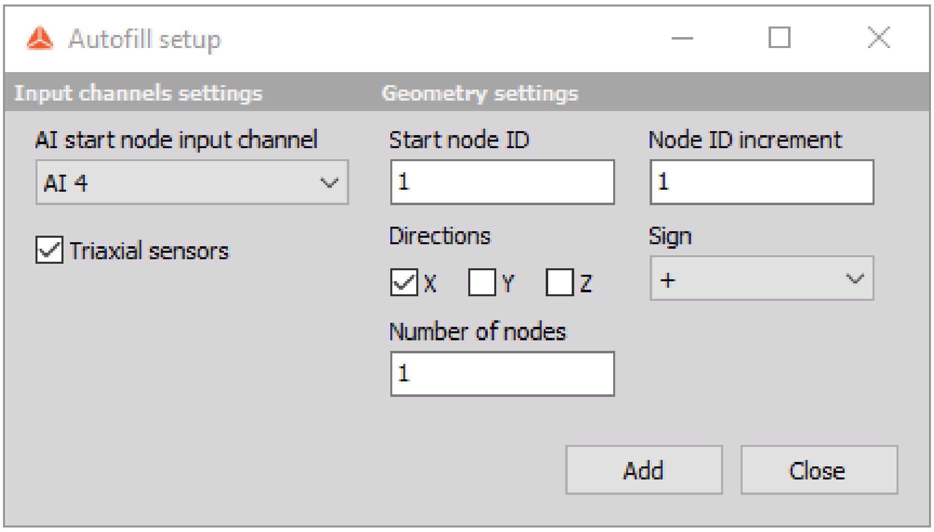
Indicate the unit for the related Input response channel. Changes to the Unit of Input response channels are global changes and will affect all usages of the related channels.

Scaling

Scaling is a read-only parameter that indicates the Scaling factor that will be used in order to get correct values in the specified Output unit.

14.2.2 Autofill setup

By using Autofill multiple response channels can be added at the same time if the Input channels are AI (Analog Input) channels.



Similar to the Autofill feature described under the Modal Test section: 6.5 Autofill setup, response DOFs can be automatically added via the Autofill setup dialog.

AI start node input channel

Defines the first AI channel to use as an Input response channel.

Triaxial sensors

A checkbox that indicates whether the used AI channels relate to uniaxial sensors or triaxial sensors. If the checkbox is enabled then all used Directions can be selected and not only one.

Important:
If you wish to use Autofill (for response channels) for triaxial sensors you must connect the response channels (Triaxial accelerometers) in a manner of: 1st sensor X, Y, Z, 2nd sensor X, Y, Z, and so on.

Start Node ID
Defines the starting point Node ID of the structure

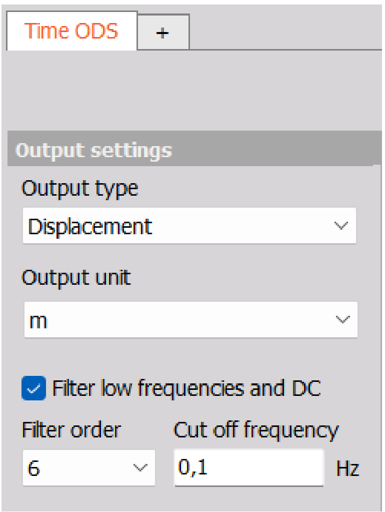
Node ID increment
Sets the increment by which the Node ID number will advance from one DOF to the next.

Direction(s)
Select the direction(s) of the measurement (if Triaxial response you can select multiple).

Sign
Defines if the excitation will be positive or negative regarding the Direction.

Number of nodes
Defines how many nodes that will be measured at the same time. The Autofill setup will add 1-3 Response channels for each node depending on how many Directions that have been selected.

14.2.3 Output settings



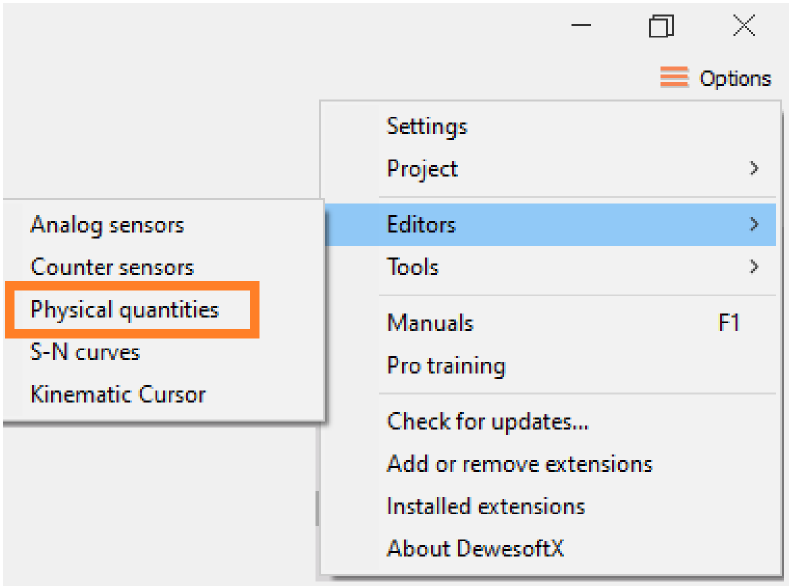
Time ODS output settings are used to set the output physical quantity and unit, possibly together with an enabled DC-filter.

Output type
The Output type defines the physical quantity of the output response channels.
The user can select between:

- Displacement
- Velocity
- Acceleration

If the physical quantity of the Input channels is different from the selected Output type, then the Input channels will be converted to have the Output type.
For example, If the Input channels have acceleration as their physical quantity, and the Output type is set to Displacement, then the input channels will get double integrated in order to convert them to represent displacement.

Output unit
The Output unit defines the unit of the output response channels. Based on the selected Output Type, the user can select between a list of related units. The list of related units can be edited in the Physical Quantity Editor:



Units can be modified and added for physical quantities under Options -> Editors -> Physical quantities.

The default defined list of units are shown below:

- Displacement
    - m (meters)
    - km (kilometers)
    - dm (decimeters)
    - cm (centimeters)
    - mm (millimeters)
    - um (micrometers)
    - in (inches)
    - ft (feet)
    - yd (yards)
    - mi (miles)
    - nmi (nautical miles)
- Velocity
    - m/s (meters per second)

- mm/s (millimeters per second)
- km/h (kilometers per hour)
- mph (miles per hour)
- knot (nautical miles per hour)
- ips (inches per second)

- Acceleration
  - m/s2 (meters per second squared)
  - g (gravitational acceleration)

If the selected Output unit is different from the Input channel unit then value scaling will be performed - converting the input unit to the desired output unit.

Filter low frequencies and DC and Filter high frequencies

If the physical quantity of the Input channels is different from the selected Output type, the required physical quantity conversion is done by time integration/differentiation filters.

Which time filters are required for the different conversions are illustrated in the table below.

Physical quantity Input / Output type	Acceleration	Velocity	Displacement
Acceleration	None	Integration	Double integration
Velocity	Derivation	None	Integration
Displacement	Double derivation	Derivation	None

I/O physical quantity transformation by integration and differentiation processing.

If integration filters are required for conversion then the checkbox 'Filter low frequencies and DC' will be available.
Time integration and double integration will amplify lower frequency components. If such lower frequency components only consist of irrelevant noise the user has the ability to remove those components by enabling the 'Filter low frequencies and DC' checkbox.

If derivation filters are required for conversion then the checkbox 'Filter high frequencies' will be available.
Time derivation and double derivation will amplify upper frequency components. If such upper frequency components only consist of irrelevant noise the user has the ability to remove those components by enabling the 'Filter high frequencies' checkbox.

Filter order

The Filter order determines the strength of the filters used to cut-off either the low frequencies and DC or the high frequencies, depending on which time filter is required to obtain the desired Output type.

The Filter order can be set from 1 to 10 and the frequency cut-off slope will be approximately 20 dB per order.

Cut-off frequency

The Cut-off frequency determines at which frequency the filters for Filter low frequencies and DC or Filter high frequencies will begin to cut-off the output signals with a rate/strength defined by the Filter order.

15. Warranty information

Notice
The information contained in this document is subject to change without notice.

Note:
Dewesoft d.o.o. shall not be liable for any errors contained in this document. Dewesoft MAKES NO WARRANTIES OF ANY KIND WITH REGARD TO THIS DOCUMENT, WHETHER EXPRESS OR IMPLIED. DEWESOFT SPECIFICALLY DISCLAIMS THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. Dewesoft shall not be liable for any direct, indirect, special, incidental, or consequential damages, whether based on contract, tort, or any other legal theory, in connection with the furnishing of this document or the use of the information in this document.

The copy of the specific warranty terms applicable to your Dewesoft product and replacement parts can be obtained from your local sales and service office. To find a local dealer for your country, please visit https://dewesoft.com/support/distributors.

15.1 Calibration

Every instrument needs to be calibrated at regular intervals. The standard norm across nearly every industry is annual calibration. Before your Dewesoft data acquisition system is delivered, it is calibrated. Detailed calibration reports for your Dewesoft system can be requested. We retain them for at least one year, after system delivery.

15.2 Support

Dewesoft has a team of people ready to assist you if you have any questions or any technical difficulties regarding the system. For any support please contact your local distributor first or Dewesoft directly.

Dewesoft d.o.o.
Gabrsko 11a
1420 Trbovlje Slovenia

Europe Tel.: +386 356 25 300
Web: http://www.dewesoft.com
Email: Support@dewesoft.com
The telephone hotline is available Monday to Friday from 07:00 to 16:00 CET (GMT +1:00)

15.3 Service/repair

The team of Dewesoft also performs any kinds of repairs to your system to assure a safe and proper operation in the future. For information regarding service and repairs please contact your local distributor first or Dewesoft directly on https://dewesoft.com/support/rma-service.

15.4 Restricted Rights

Use Slovenian law for duplication or disclosure. Dewesoft d.o.o. Gabrsko 11a, 1420 Trbovlje, Slovenia / Europe.

15.5 Printing History

Version 2.0.0, Revision 217 Released 2015 Last changed: 23. July 2018 at 16:54.

15.6 Copyright

15.7 Trademarks

We take pride in our products and we take care that all key products and technologies are registered as trademarks all over the world. The Dewesoft name is a registered trademark. Product families (KRYPTON, SIRIUS, DSI, DS-NET) and technologies (DualCoreADC, SuperCounter, GrandView) are registered trademarks as well. When used as the logo or as part of any graphic material, the registered trademark sign is used as a part of the logo. When used in text representing the company, product or technology name, the ® sign is not used. The Dewesoft triangle logo is a registered trademark but the ® sign is not used in the visual representation of the triangle logo.

16. Safety instructions

Your safety is our primary concern! Please be safe!

16.1 Safety symbols in the manual

Warning
Calls attention to a procedure, practice, or condition that could cause the body injury or death

Caution
Calls attention to a procedure, practice, or condition that could possibly cause damage to equipment or permanent loss of data.

16.2 General Safety Instructions

Warning

The following general safety precautions must be observed during all phases of operation, service, and repair of this product. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended use of the product. Dewesoft d.o.o. assumes no liability for the customer's failure to comply with these requirements.

All accessories shown in this document are available as an option and will not be shipped as standard parts.

16.2.1 Environmental Considerations

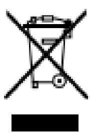
Information about the environmental impact of the product.

16.2.2 Product End-of-Life Handling

Observe the following guidelines when recycling a Dewesoft system:

16.2.3 System and Components Recycling

Production of these components required the extraction and use of natural resources. The substances contained in the system could be harmful to your health and to the environment if the system is improperly handled at its end of life! Please recycle this product in an appropriate way to avoid unnecessary pollution of the environment and to keep natural resources.



This symbol indicates that this system complies with the European Union's requirements according to Directive 2002/96/EC on waste electrical and electronic equipment (WEEE). Please find further information about recycling on the Dewesoft web site www.dewesoft.com

Restriction of Hazardous Substances

This product has been classified as Monitoring and Control equipment and is outside the scope of the 2002/95/EC RoHS Directive. However, we take care of our environment and the product is lead-free.

16.2.4. General safety and hazard warnings for all Dewesoft systems

Safety of the operator and the unit depend on following these rules.

- Use this system under the terms of the specifications only to avoid any possible danger.
- Read your manual before operating the system.
- Observe local laws when using the instrument.
- DO NOT touch internal wiring!
- DO NOT use higher supply voltage than specified!
- Use only original plugs and cables for harnessing.
- You may not connect higher voltages than rated to any connectors.
- The power cable and connector serve as Power-Breaker. The cable must not exceed 3 meters, the disconnect function must be possible without tools.
- Maintenance must be executed by qualified staff only.
- During the use of the system, it might be possible to access other parts of a more comprehensive system. Please read and follow the safety instructions provided in the manuals of all other components regarding warning and security advice for using the system.
- With this product, only use the power cable delivered or defined for the host country.
- DO NOT connect or disconnect sensors, probes or test leads, as these parts are connected to a voltage supply unit.
- Ground the equipment: For Safety Class 1 equipment (equipment having a protective earth terminal), a non-interruptible safety earth ground must be provided from the mains power source to the product input wiring terminals.
- Please note the characteristics and indicators on the system to avoid fire or electric shocks. Before connecting the system, please read the corresponding specifications in the product manual carefully.
- The inputs must not, unless otherwise noted (CATx identification), be connected to the main circuit of category II, III and IV.
- The power cord separates the system from the power supply. Do not block the power cord, since it has to be accessible for the users.
- DO NOT use the system if equipment covers or shields are removed.
- If you assume the system is damaged, get it examined by authorized personnel only.
- Adverse environmental conditions are Moisture or high humidity Dust, flammable gases, fumes or dissolver Thunderstorm or thunderstorm conditions (except assembly PNA) Electrostatic fields, etc.
- The measurement category can be adjusted depending on module configuration.
- Any other use than described above may damage your system and is attended with dangers like short-circuiting, fire or electric shocks.
- The whole system must not be changed, rebuilt or opened.
- DO NOT operate damaged equipment: Whenever it is possible that the safety protection features built into this product have been impaired, either through physical damage, excessive moisture, or any other reason, REMOVE POWER and do not use the product until the safe operation can be verified by service-trained personnel. If necessary, return the product to Dewesoft sales and service office for service and repair to ensure that safety features are maintained.
- If you assume a more riskless use is not provided anymore, the system has to be rendered inoperative and should be protected against inadvertent operation. It is assumed that a more riskless operation is not possible anymore if the system is damaged obviously or causes strange

noises. The system does not work anymore. The system has been exposed to long storage in adverse environments. The system has been exposed to heavy shipment strain.

- Warranty void if damages caused by disregarding this manual. For consequential damages, NO liability will be assumed!
- Warranty void if damage to property or persons caused by improper use or disregarding the safety instructions.
- Unauthorized changing or rebuilding the system is prohibited due to safety and permission reasons (CE).
- Be careful with voltages >25 VAC or >35 VDC! These voltages are already high enough in order to get a perilous electric shock by touching the wiring.
- The product heats during operation. Make sure there is adequate ventilation. Ventilation slots must not be covered!
- Only fuses of the specified type and nominal current may be used. The use of patched fuses is prohibited.
- Prevent using metal bare wires! Risk of short circuit and fire hazard!
- DO NOT use the system before, during or shortly after a thunderstorm (risk of lightning and high energy over-voltage). An advanced range of application under certain conditions is allowed with therefore designed products only. For details please refer to the specifications.
- Make sure that your hands, shoes, clothes, the floor, the system or measuring leads, integrated circuits and so on, are dry.
- DO NOT use the system in rooms with flammable gases, fumes or dust or in adverse environmental conditions.
- Avoid operation in the immediate vicinity of high magnetic or electromagnetic fields, transmitting antennas or high-frequency generators, for exact values please refer to enclosed specifications.
- Use measurement leads or measurement accessories aligned with the specification of the system only. Fire hazard in case of overload!
- Do not switch on the system after transporting it from a cold into a warm room and vice versa. The thereby created condensation may damage your system. Acclimatise the system unpowered to room temperature.
- Do not disassemble the system! There is a high risk of getting a perilous electric shock. Capacitors still might be charged, even if the system has been removed from the power supply.
- The electrical installations and equipment in industrial facilities must be observed by the security regulations and insurance institutions.
- The use of the measuring system in schools and other training facilities must be observed by skilled personnel.
- The measuring systems are not designed for use in humans and animals.
- Please contact a professional if you have doubts about the method of operation, safety or the connection of the system.
- Please be careful with the product. Shocks, hits and dropping it from already- lower level may damage your system.
- Please also consider the detailed technical reference manual as well as the security advice of the connected systems.
- This product has left the factory in safety-related flawlessness and in proper condition. In order to maintain this condition and guarantee safety use, the user has to consider the security advice and warnings in this manual.

EN 61326-3-1:2008

IEC 61326-1 applies to this part of IEC 61326 but is limited to systems and equipment for industrial applications intended to perform safety functions as defined in IEC 61508 with SIL 1-3.

The electromagnetic environments encompassed by this product family standard are industrial, both indoor and outdoor, as described for industrial locations in IEC 61000-6-2 or defined in 3.7 of IEC 61326-1.

Equipment and systems intended for use in other electromagnetic environments, for example, in the process industry or in environments with potentially explosive atmospheres, are excluded from the scope of this product family standard, IEC 61326-3-1.

Devices and systems according to IEC 61508 or IEC 61511 which are considered as “operationally well-tried”, are excluded from the scope of IEC 61326-3-1.

Fire-alarm and safety-alarm systems, intended for the protection of buildings, are excluded from the scope of IEC 61326-3-1.

17. Documentation version history

Last modified: Fri 11 May 2021

Version	Date [dd.mm.yyyy]	Notes
1.0	29.05.14	☑ initial revision
1.1	08.06.15	☑ MIMO removed; Triggered, group response removed; ☑ added hint to 3.2.3 ODS ☑ Changed pictures of modal testing force transducer with more suitable one ☑ Corrected response exponential window decay lines (20%, 50%, ...)
V21-1	11.05.2021	☑ Updated screenshots with the latest version (2021.2) ☑ Added Modal analysis ☑ Updated examples
V21-3	07.10.2021	☑ Updated section 4.2 Shaker ☑ Updated section 6.1 Auto-generated displays ☑ Added section 6.1.1-3 for generated displays
V21-4	16.12.2021	☑ Added Time ODS, section 12 ☑ Updated "ODS" to Spectral ODS and Time ODS ☑ Updated pictures to match V2021.6 ☑ Added Geometry editor tab information ☑ MT setup Index changed to Node ID, Geometry editor Label change to Node ID ☑ Additional MIF information about NMIF.
V22-1	11.05.2022	☑ Updated Modal analysis information: Added new sections 8, 9 and 10.
V23-1	15.07.2023	☑ Added caption text to all pictures ☑ Updated some of the pictures ☑ Updated ODS section to include ODS FRFs and Transmissibility ☑ Added section for 'Mounting of the test structure' ☑ Added section for 'The differences between MT and MA' ☑ Added section for 'Modal geometry widget properties'