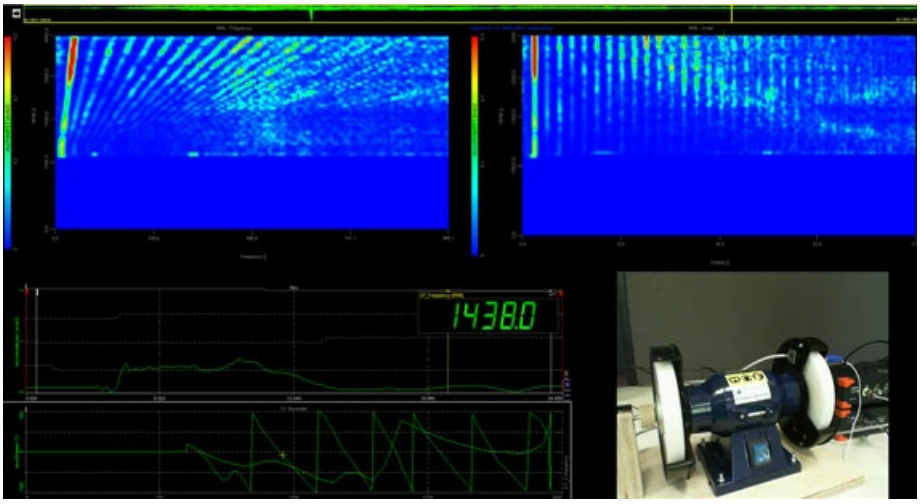
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Order Tracking Measurement and Analysis



Order Tracking Analysis Theory

Analysis of vibration signals from rotating machines is often preferred in terms of order spectrum rather than the frequency spectrum. An order spectrum gives the amplitude and the phase of the signal as a **function of harmonic order of the rotation frequency**. This means that a harmonic or subharmonic order component remains in the same analysis line independent of the speed of the machine. The technique is called **tracking** as the rotation frequency is being tracked and used for analysis.

The order tracking method is used to extract the harmonic components related to the rotational frequency of the machine. The machine vibration pattern is a mixture of excitation frequencies, usually related to rotational speed (such as unbalance, eccentricity, bearing faults and others) and machine response function, which relates to machine natural frequencies based on the structure and mounting of that machine.

With order extraction, we can see a specific harmonic component which relates to a certain machine fault. That is - the first order (harmonic) usually relates to unbalance of the machine, the second harmonic often relates to eccentricity, such as if we have for example 9 rotor blades, the 9th harmonic relates to errors on the blades. Or, if we have for example 31 teeth on a gear, then the 31st harmonic will show the gear mesh frequency.

These are excitations, forces which produce vibration accelerations. The ratio between excitation and system response is defined by the system transfer curve. The final measured vibration of the system is a product of the excitation force and the system transfer curve. Since the transfer curve is fixed, we get different responses for excitations at different rotation speeds. When the excitation passes natural frequency, we get the so-called resonance with increased vibration amplitudes, which could be fatal to the machine.

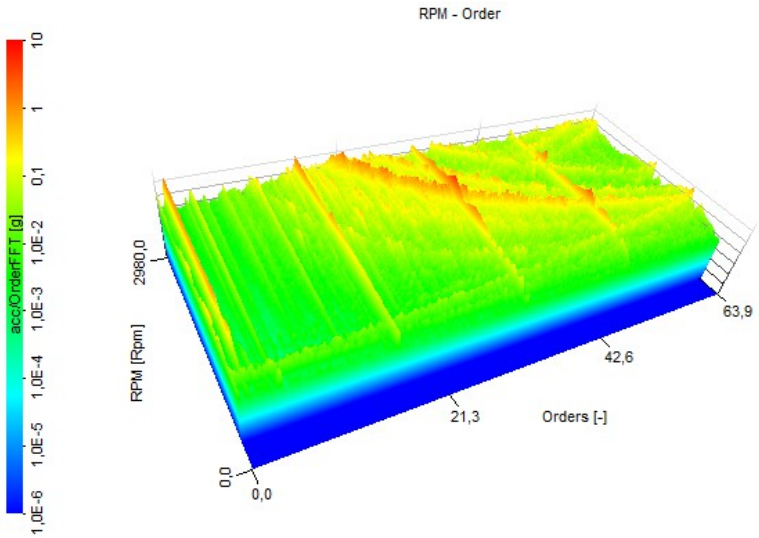


Image 1: Example of Order tracking 3D display

Orders in practical applications

This page should give you a rough idea what 1st, 2nd, ... order means and what might be their possible source.

1st order = imbalance

The first order is the shaft frequency, so if the first order is the main reason for high vibration, this is related to an unbalanced shaft or blade.

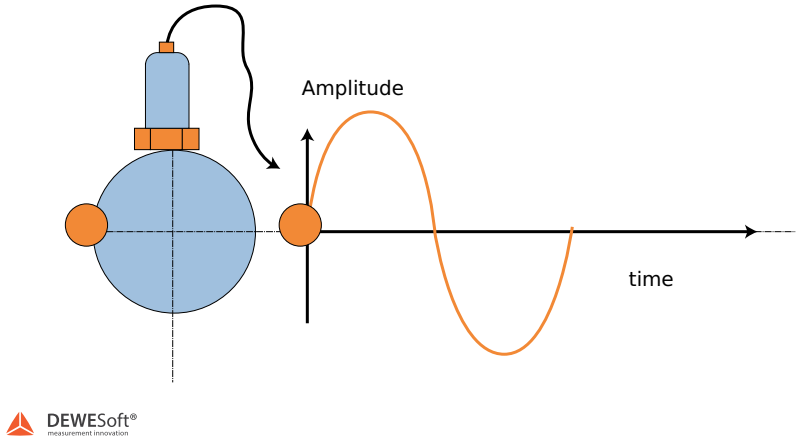


Image 2: Explanation of 1st order

Imagine a blade or shaft or any rotating part that has a higher weight at one side. This weight will rotate with exactly the rotational speed (1st order), create a force and, therefore, a vibration frequency which is exactly the rotation speed or first order. So high amplitudes of first orders indicate an unbalanced system.

1st and 2nd order = misalignment

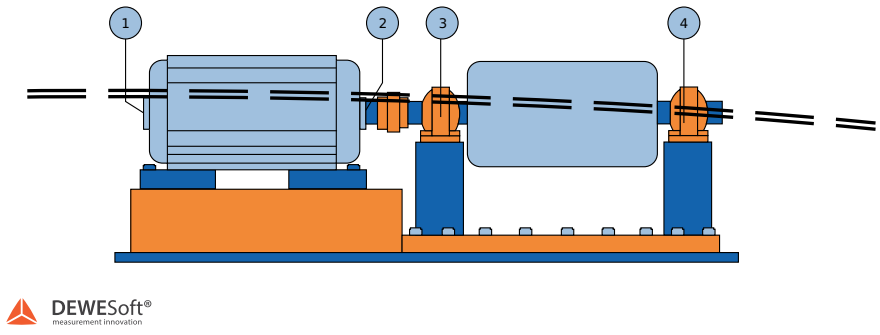


Image 3: Explanation of 1st & 2nd order

If a high second order is observed in the vibration spectrum of a machine, it often indicates a misalignment of two coupled engines. So, two times per revolution (2nd order) the shaft is bent and causes a vibration force, which is transmitted to the mechanical structure and creates a vibration.

Diesel and gasoline engines

In a diesel and gasoline engines, we can observe that 2nd, 3rd or 6th order are almost all the time dominant, why?

- It depends on the cylinder count of the engine. Let's assume we have a 4 cylinder 4 stroke engine. One cylinder is fired every 2 revolutions, so we would get 0.5 order vibration if we would have a 1 cylinder engine.
- With a 4 cylinder engine the firing of the 4 cylinders is distributed over 4 revolutions, 2 rev/4 = 0,5 rev so one of the 4 cylinders will fire every 0,5 revolutions. This will lead to high second order vibration.
- A 6 cylinder 4 stroke engine will produce high 2 rev/6 = 0.33rev Ã¢â€ â€™ 3rd order.

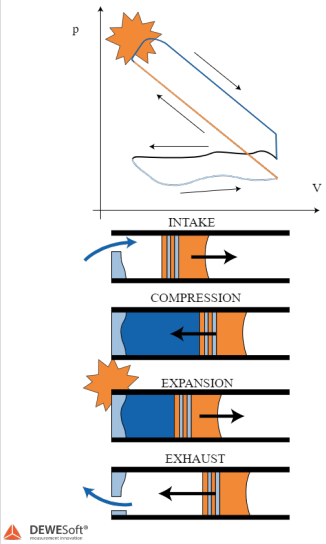


Image 4: Explanation of other orders

What is Order Tracking Analysis

Rotating machines produce repetitive vibrations and acoustic signals related to the rotational speed. These relationships are not always obvious with standard dynamic signal analysis, particularly with variations in the rotational speed. A measurement technique called order analysis is the secret to sorting out all the many signal components that a rotating machine can generate.

Order tracking is a family of signal processing tools aimed at transforming a measured signal from the time domain to angular (or order) domain. These techniques are applied to asynchronously sampled signals (i.e. with a constant sample rate in Hertz) to obtain the same signal sampled at constant angular increments of a reference shaft. In some cases, the outcome of the order tracking is directly the Fourier transform of such angular domain signal, whose frequency counterpart is defined as "order". Each order represents a fraction of the angular velocity of the reference shaft.

Order tracking is based on a velocity measurement, generally obtained by means of a tachometer or encoder, needed to estimate the instantaneous velocity and/or the angular position of the shaft.

Rotating machines under operational conditions require additional analysis such as order tracking. Compared to normal FFT the spectrum is based on orders instead of frequency (time). With this method, you can separate frequency components which are related to engine speed and those that are related to the structure.

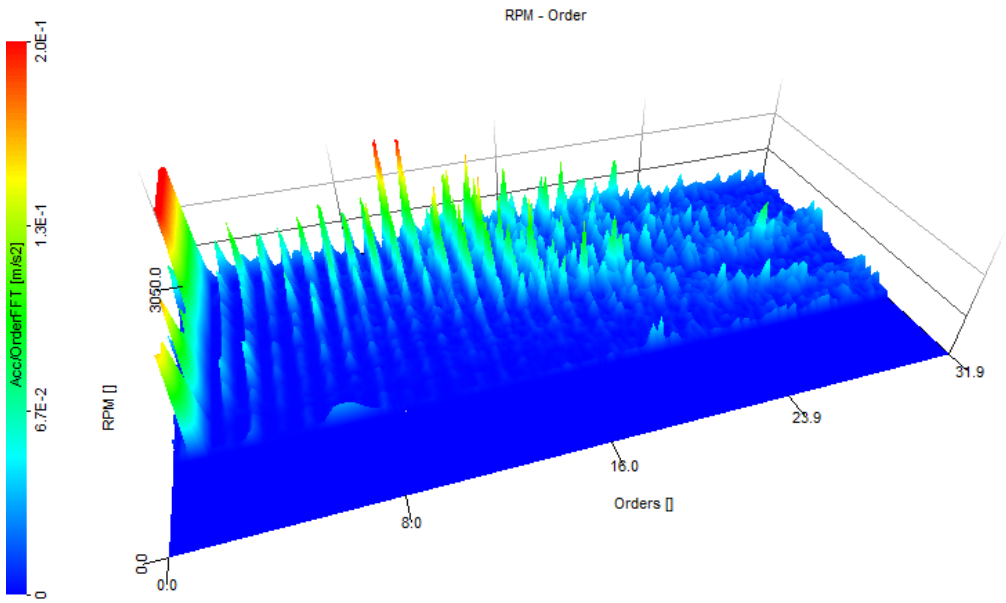


Image 5: 3D graph of Orders regarding different Speed's

Dewesoft X software provides a powerful and very easy-to-use order tracking module for fast and efficient results. The data and the RPM information is recorded simultaneously in the time domain and re-sampled in the order tracking module. Therefore, we can show a narrow band FFT, waterfall spectrum, and still keep all other convenient functions in the time domain.

The classical problem of smearing of the frequency components caused by speed variations of the machine is solved by using order analysis. In situations where the frequency components from a normal frequency analysis are smeared together, proper diagnosis is order analysis.

Of particular interest is the analysis of the vibrations during a run-up or a coast-down of a machine in which case the structural resonances are excited by the fundamental or the harmonics of the rotational frequencies of the mechanical system. Determination of the critical speeds, where the normal modes of the rotating shaft are excited, is very important on large machines such as turbines and generators.

Use of an FFT analyser in the normal sampling mode with a fixed sampling frequency (non-tracking) and plotting of the spectrum at certain fixed steps in the rotation speed of the machine gives the Campbell diagram (3D waterfall type of a plot, where vibration levels as a function of frequency are plotted against rotation speed (RPM) of the machine (plotted vertically). This means that the harmonic components appear on radial lines through the point (0 Hz, 0 RPM) while structural resonances appear on vertical straight lines (constant frequency lines). The smearing of the

components, which appears because the time window used for the individual spectra represents a certain sweep in the speed, is, however, a disadvantage. The power of the components becomes spread over several lines. In particular, high-frequency components in the spectrum, such as tooth mesh frequencies, might be smeared so much that details in sideband structures are lost in the analysis. This is the main reason why order analysis is used instead.

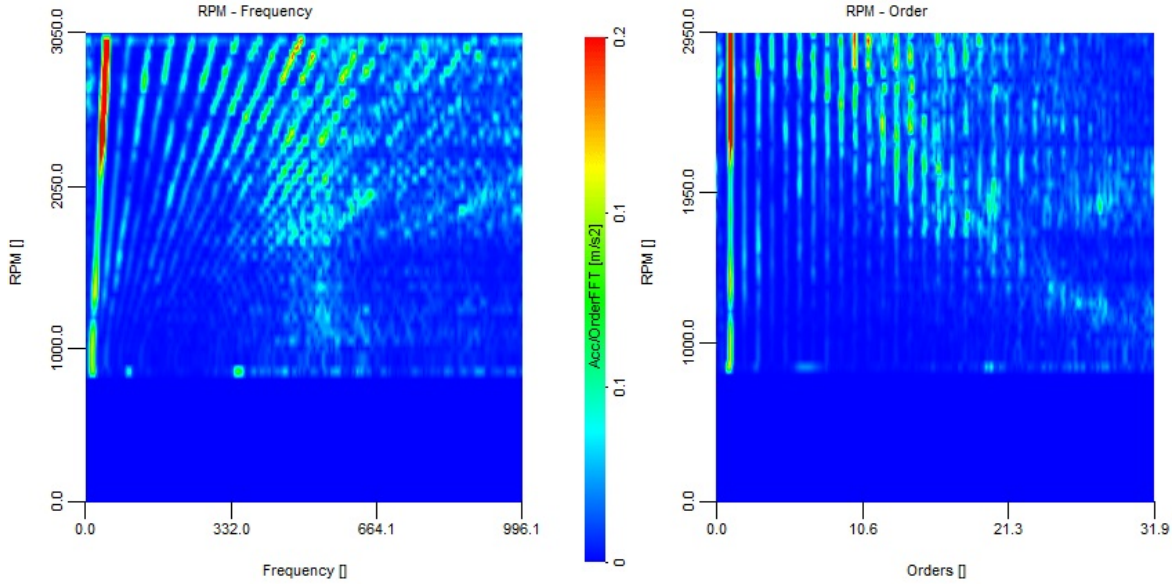


Image 6: Flat projection comparison of Frequency waterfall vs. Speed and Order waterfall vs. Speed

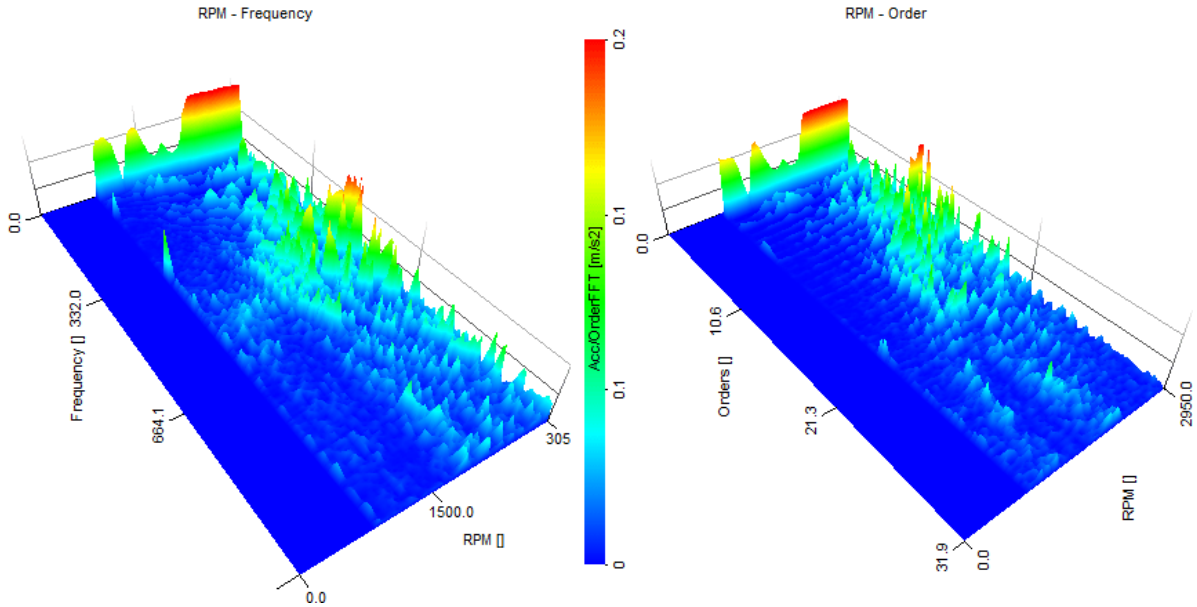


Image 7: 3D projection comparison of Frequency waterfall vs. Speed and Order waterfall vs. Speed

For order tracking, the time record is measured in revolutions and the corresponding FFT spectrum is measured in orders or in frequency. Just like the resolution, delta f [Hz], of the frequency spectrum, equals 1/T, where T [s] is seconds per FFT-record, the resolution of the tracked analysis, delta ord [ORD], equals 1/rev, where rev [REV] is revolutions per FFT-record. For the analysis with one or more revolutions per record, the resolution of the spectrum is equal to or better than 1 ORD. The result of the analysis is a high-resolution order-spectrum, where the individual orders or fractions of orders, relate directly to the various rotating parts of the machinery.

Tracking analysis (with use of an FFT analyser) is an analysis by which the harmonic pattern of the vibration signal from a rotating machine is stabilized in certain lines independent of speed variations. This means that all the power of a certain harmonic is concentrated in one line and the smearing that would result in normal analysis is avoided.

Why Do We Need Order Tracking Module ?

Before we start explaining all the different options of the setup, let's check at first why we need the order tracking module.

An electrical scooter motor standing on a rubber foam is analysed. The RPM is controlled by DC voltage and measured by an optical probe (reflective sticker on a shaft) and the vibration by an acceleration sensor mounted on top.

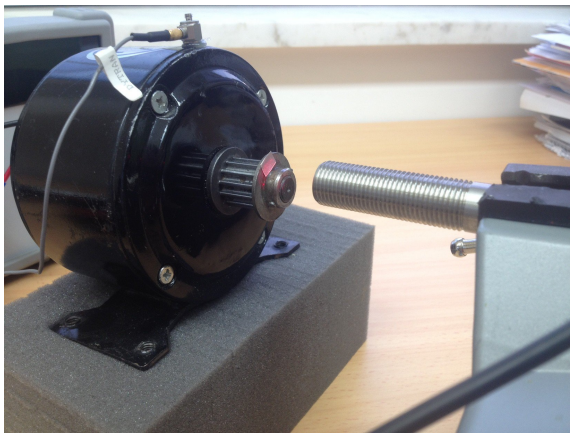


Image 8: Electric motor equipped with acceleration sensor and tacho

FFT spectrum at 800 rpm

In the first example, the engine is running at a constant speed of 800 rpm.

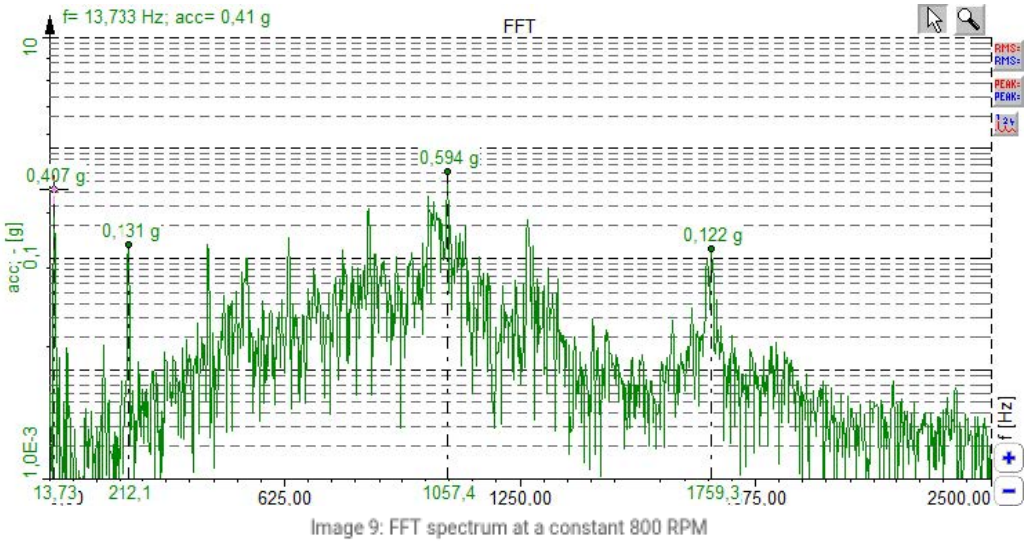


Image 9: FFT spectrum at a constant 800 RPM

When we look at the vibration spectrum, the lowest frequency of the highest peak is 13,73 Hz (13,73 * 60 = 823 rpm), which is most likely the first order. The next peak could be the 16th order (13,73 * 16 = 219,7 Hz).

When we increase the RPM now, the distance between some of the spectral lines gets bigger. We call the lines moving with RPM harmonics. They can be calculated by multiplying the base frequency with an integer number.

FFT spectrum at 1950 rpm

Then we run the engine at a constant speed of 1950 rpm.

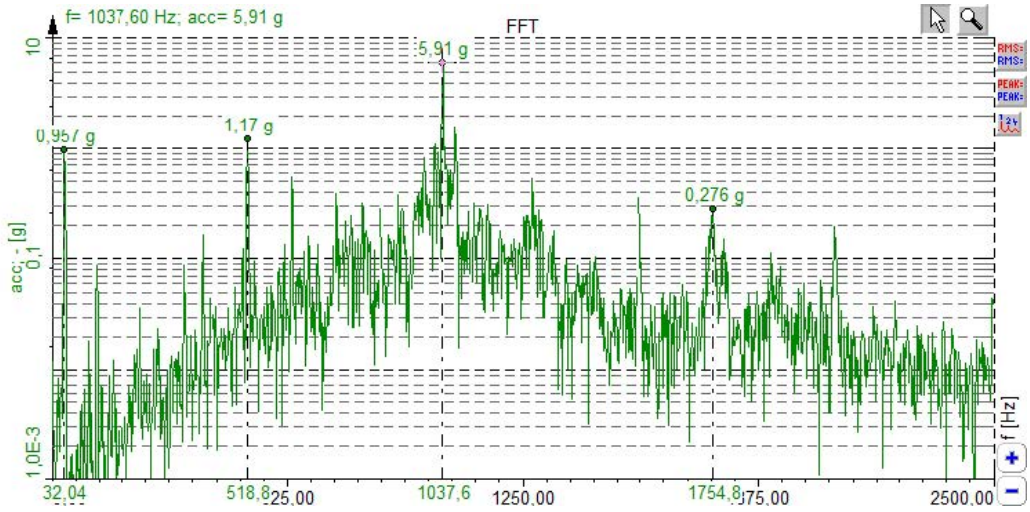


Image 10: FFT spectrum at a constant 1950 RPM

The first order is again the lowest frequency peak at 32,04 Hz (32,04 Hz * 60 = 1922 rpm). Around 518 Hz, is most probably the 16th order. The 1754 Hz more or less stays the same and doesn't seem to be related to rpm (compare with 800 rpm measurement).

So, the spectrum consists of harmonics of the rotation speed and other frequencies.

FFT spectrum during runup / coastdown

Of course, it would take too much time to make an FFT for each RPM, so we can try to use the FFT during engine runup or coast down. The following experiment shows the FFT while the engine is slowing down from 1700 to about 1400 rpm.

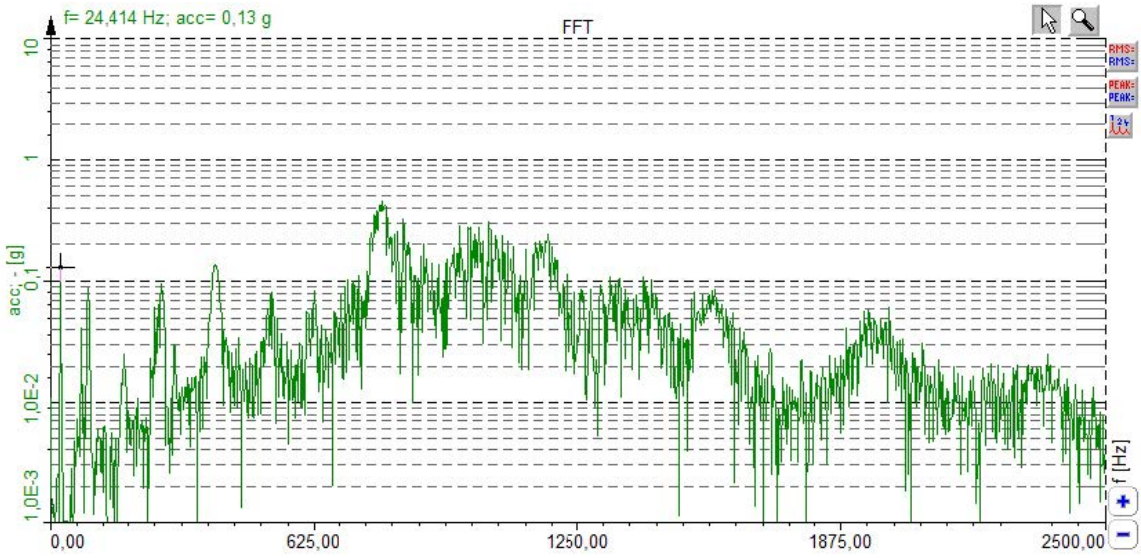
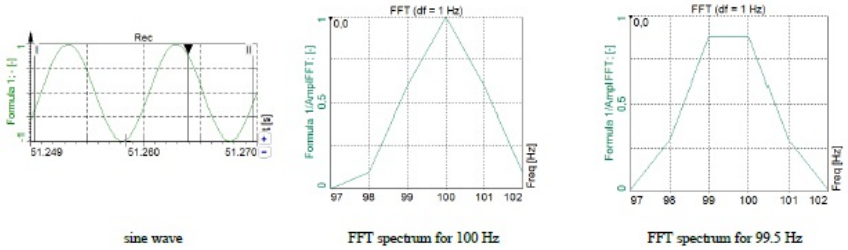


Image 11: FFT of an engine while in coast-down from 1700 RPM to 1400 RPM

When you compare the spectrum with the ones before, you see that there are no sharp lines anymore. The reason is that the rpm is changing while the FFT still needs time for calculation. This effect is called smearing.

Furthermore, from its nature, the FFT always has a frequency and an amplitude error.

To demonstrate, we generate a simple 100 Hz sine wave using the Dewesoft X mathematics (sine(100)). When we use a sampling frequency of 2048 Hz and an FFT with 1024 points we get (because of Nyquist criteria) a line resolution of exactly 1 Hz. Amplitude and frequency in the FFT are correct. Now we change the sine wave to 99.5 Hz. The energy of the peak is now distributed to both neighbor lines at 99 and 100 Hz, therefore, the amplitude is also not exact anymore.



sine wave | FFT spectrum for 100 Hz | FFT spectrum for 99.5 Hz

Image 12: Example of FFT Smearing

In real life, it is very unlikely that the input signal will be at a constant frequency directly at the FFT line. Different windowing algorithms are designed for each application (flat top for example shows the correct amplitude).

In Dewesoft X, the FFT calculation time window is shown as a yellow frame in the overview instrument in Analyse mode if you click on the FFT.

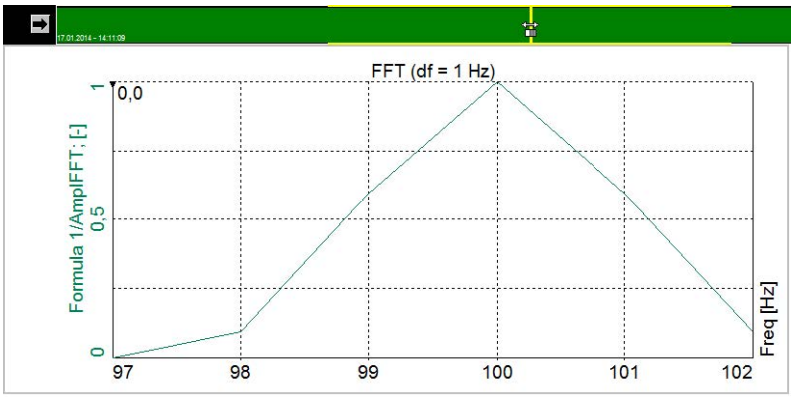


Image 13: Calculation time window adjustment

Manual order tracking would mean setting up each constant rpm sequentially, e.g. 600, 700, 800 then manually extracting the peaks from the FFT, and sorting them out to find the orders. You cannot be absolutely sure you will catch the right peaks (some frequency lines are not related to rpm and you can mix them up).

Using FFT during run-up/coast-down would result in unprecise measurement because of smearing and other FFT disadvantages.

With the Order tracking module of Dewesoft X, the order analysis is very easy to set up and easy to use.

Dewesoft X Order Tracking Analysis Module

The Dewesoft X order tracking module is used for e.g. vibration analysis on engines or other rotating machinery, both in development and optimization. With the small, handy form factor of the Dewesoft instruments (DEWE-43, SIRIUSi), it is also a smart portable solution for service engineers coping with failure detection.

The order tracking module is included in the DSA package (along with other modules like torsional vibration, frequency response function, ...).

How does it work? - Usually a run up or coast down of the engine is done. The measured vibration sensor data is calculated according to the angle sensor data, split up into orders, which can then be analysed across the whole rpm range. With order tracking the frequencies can be separated into those related to the RPM and spurious ones. The powerful visualisation and mathematic options lead to a clear picture of the situation.

Furthermore, calculations can also be done offline (after the measurement), like with most of the other modules, e.g. if a very high sampling rate is required or the CPU of the used computer simply is too weak.

If the powerful integrated post-processing features of Dewesoft X are not enough, you can even export the data to several different file formats.

System overview

Depending on what to analyze, e.g. acceleration sensors, microphones or pressure sensors are used to the analog input to measure sound/vibration. If they are e.g. voltage or ICP type, they are connected to the SIRIUS ACC amplifier or DEWE-43 with MSI-ACC adapter.

For the angle sensor, you have various possibilities: you can use either an Encoder with individual pulse count, CDM- 360/-720 or a simple tacho probe with 1 pulse/revolution (TTL or analog output) or 60-2, 36-2 tooth wheel sensor. If the RPM is changing slowly and the phase information is not of interest, the RPM can also be derived from any kind of signal (e.g. 0...20mA, which equals 0...6000rpm) or data channel, e.g. the CAN bus of a car.

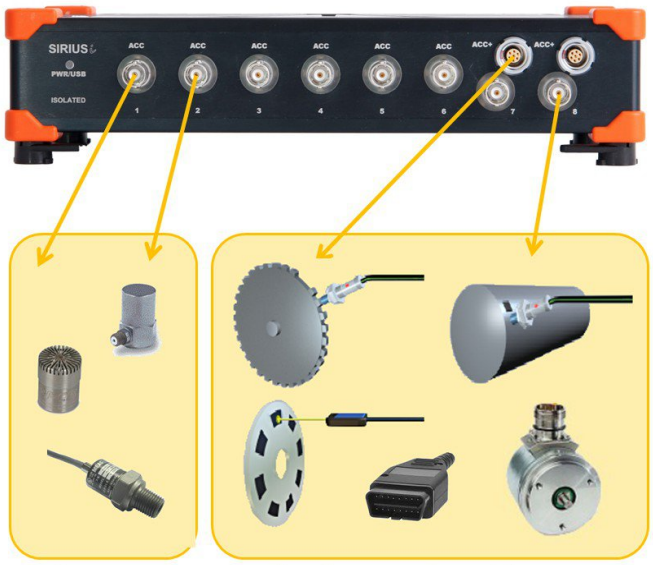


Image 14: Different signal acquisition options

General setup

To add Order tracking module in Dewesoft X go into **Measure** mode, **Channel setup** and click on **More...** Search for **Order tracking** and select it.

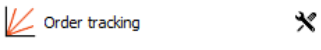


Image 15: Order tracking icon

The input mask of the order tracking module is split into the following sections:

Input	channels: switch the output channels with arrow buttons and see preview values
Output	channels: switch the output channels with arrow buttons and see preview values
Frequency channel setup	defines the type of angle sensor (e.g. Enc-512, Tacho, Geartooth)
Calculation criteria - frequency limits	sets the RPM limits, delta RPM, runup/coastdown/both
Order FFT setup	specify maximum orders and the resolution (e.g. 1/16th order), order FFT vs. time, order FFT vs. RPM and order domain harmonics
Time FFT setup	defines the change calculation method from resampled data to FFT, time-domain harmonics and update rate on RPM change
Common properties	define the harmonic list, FFT window, update criteria and how to average data

Analog input signal to analyze

In most of the cases, the analysis will be done with a vibration sensor. Just enable the desired channel in the list on the left upper side of the module setup. Basically, any analog input can be used, here are some examples:

- acceleration sensor
- microphone
- pressure sensor
- output of the rotational vibration / torsional vibration module

Frequency channel setup

For determining the engine speed (rpm), an RPM sensor is needed. A lot of different sensors are supported.

In the **Frequency source** drop-down menu, you can choose between **Counters**, **Analog pulses** or **RPM channel. Sensor** menu will let you select the sensor you have created and saved in **Counter sensor editor.** From the **Frequency channel**, you select the channel that is connected to your sensor.

You can access the **Counter sensor editor** in **Options** / **Editors** / **Counter sensors** or by pressing the **"..."** button.

Acceptable sensors for order tracking are for example

- **Digital**
  - **Tacho probe** (1 pulse/revolution; connect to analogue or digital input)
  - **Encoder** (e.g. 1800 pulses/revolution or CDM-360 / CDM-720 or 60-2; connect to Counter input)
- **Analogue**
  - **Geartooth sensors** (36-2 or 60-2 sensor connect to an analog input)
- any **RPM channel**
  - **Math channel, analogue voltage** or **RPM from CAN** bus; but then the phase of the harmonics cannot be extracted, because there is no zero-angle information

Counters

Select Counters if you connect an Encoder to the Dewesoft instrument Counter input (usually 7pin Lemo connector).

An encoder (e.g. 1800 pulses/revolution) or CDM (CDM-360, CDM-720) or Tacho (digital = TTL levels) or tooth wheel sensor (60-2) can be used. The counter setup in the background is then controlled (locked) by the Order tracking module, the counters will not be accessible (greyed out), to prevent double-usage.

In Counter mode, you can optionally set the filter, to suppress glitches/spikes shorter than the shown value (100ns...5Î¼s). The optimal setting is derived from the following equation:

$$InputFilter[s] \leq \frac{1}{10 \cdot \frac{RPM_{max}}{60} \cdot PulsesPerRev}$$

$RPM_{max} \ldots max\ revolutions\ per\ minute\ [min^{-1}]$
$PulsesPerRev \ldots pulses\ per\ revolution\ of\ encoder$

The biggest error is caused by improper mounting of an encoder. There are different mounting errors using a coupling, such as parallel, skewed, angled. The error will appear as periodic angle/frequency deviation during constant engine speed.

The easiest way is using a tacho probe with digital output. It can be directly connected to the Dewesoft instrument's counter input and is easy to mount. For example, the optical tacho probe only requires a reflective sticker on the rotating part, see **Image 8**.

Analog pulses

If you have a tacho probe (1 pulse/rev, optic, magnetic or any other type) with analog output signal, you can just connect it to an analog input (e.g. SIRIUS-ACC module) and use the analog setting of the frequency section.

Here example signals of a magnetic and an optic probe are shown.

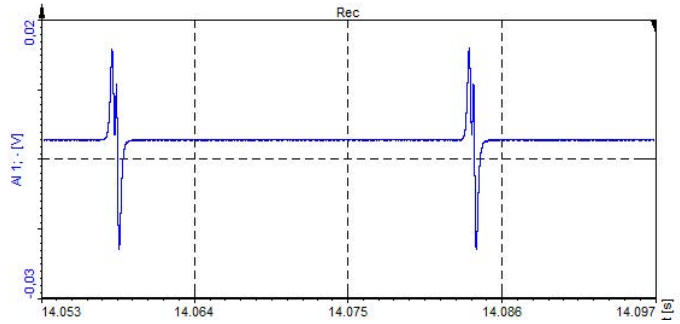


Image 16: Optic probe signal

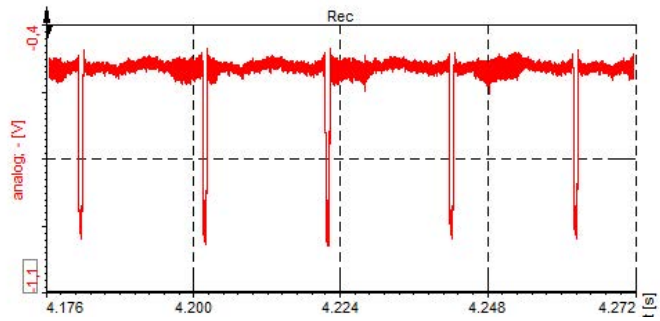


Image 17: Magnetic probe signal

Beyond that, also 60-2 and 36-2 analog signals from the crank sensor (inside nearly every vehicle) are supported.

Click the **...** button to adjust the correct trigger level. You can also use the **Find** algorithm button, which will automatically determine the best possible value. Please take care when using a magnetic probe, that also the induced voltage will change depending on the RPM, resulting in a different trigger level. Therefore perform some test runs across the interesting RPM range to find the best trigger level.

Below, an example of 60-2 analogue sensor is shown.

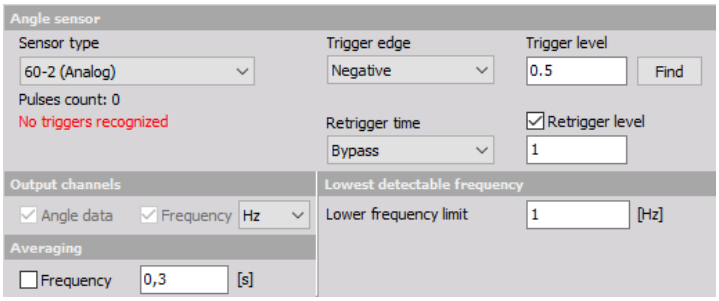


Image 18: Angle sensor math setup

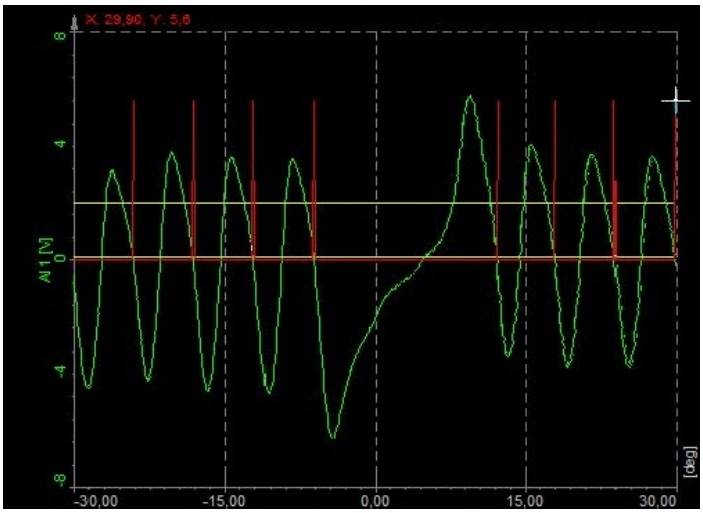


Image 19: 60-2 analogue sensor signal

HINT: If machines with highly dynamic rpm, or with a high rotational vibration are analysed (big rpm deviations during one revolution), and also high orders should be extracted, an encoder or a tacho probe with more than one pulse/rev. (180p/rev or higher) is recommended, to get higher accuracy.

Reason: The order tracking algorithm resamples the time domain data into the angle domain. If we get more information from the RPM probe, we have more pulses per revolution and the resampling to the angle domain will be much more accurate!

RPM channel

You can also use any signal or channel as input, which directly represents the RPM (e.g. 0...10V equals 0...5000 rpm).

The disadvantage, however, is, that there is no zero-angle information, and therefore extraction of the phase angles of the single orders is not possible.

Following example shows an RPM signal from CAN bus inside a vehicle (red line). Note that the sampling points are asynchronous. The blue line is the output signal of an acceleration sensor.

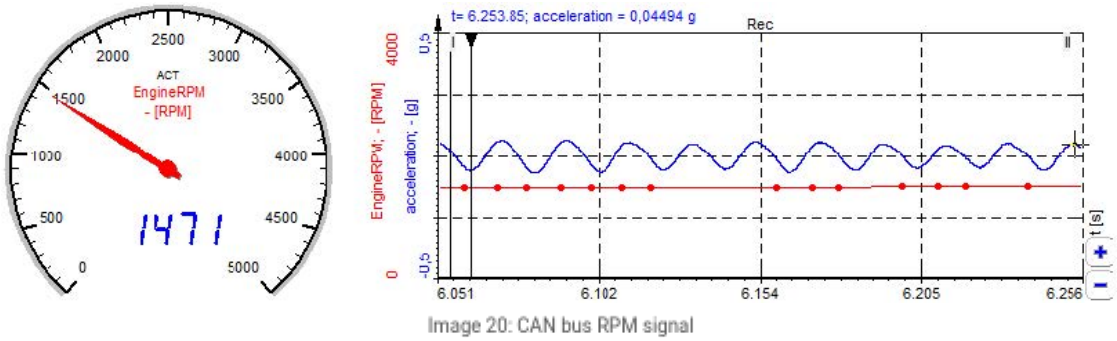


Image 20: CAN bus RPM signal

Calculation criteria - time and frequency limit

To cover the whole frequency spectrum, a run-up or a coast-down of the engine has to be performed.

Image 17 represents a recording of RPM over time. All terms that you will encounter during the setup of Order Tracking are visually presented.

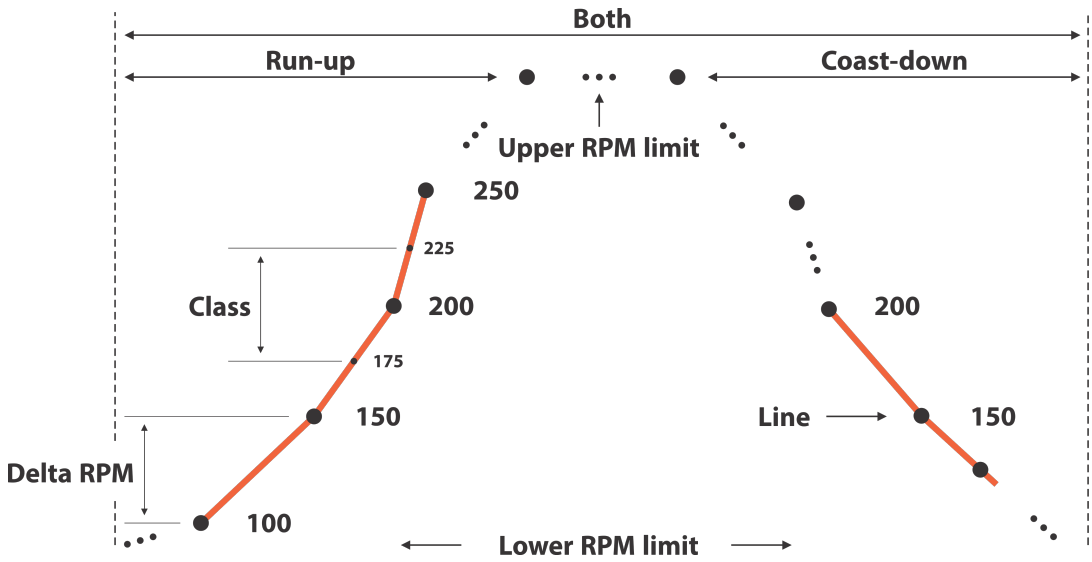


Image 21: Representation of Order tracking terminology

Calculation criteria - frequency limits

Select the **RPM limits** (upper and lower RPM limit), and whether you want to calculate the waterfall spectrum and order extraction while doing a **run-up**, **coast-down** or **both**.

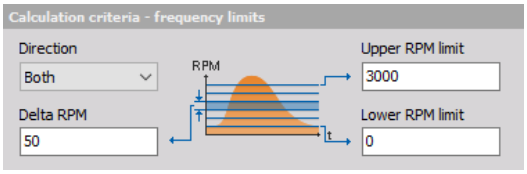


Image 22: Calculation criteria setup

Upper and lower RPM limit define the range for calculation and are used to correctly set up the resampling algorithm, depending on the max orders extracted.

Delta RPM will define when a new update of the waterfall spectrum and also the extracted order domain harmonics are calculated. In case, the RPM is not changing only channels from Time FFT setup can be calculated according to the maximum time limit setting.

Output channel calculation rate

Order data	(Order domain harmonics, Order waterfall vs. RPM, Overall RMS) are updated on delta RPM
Order FFT vs. time	is updated on each FFT calculation (when you acquire enough samples needed)
Time data	(Time domain harmonics, FFT waterfall vs. RPM) are updated on delta RPM or on an update time limit or both.

Common properties

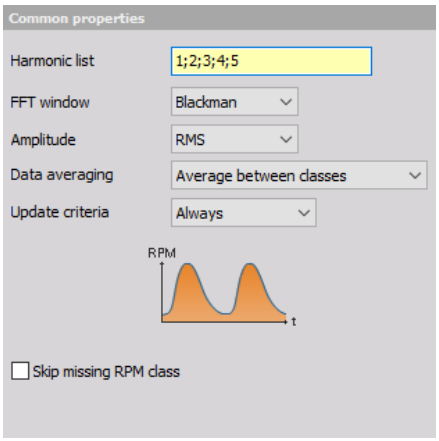


Image 23: Common properties setup

To extract the orders simply enter the wanted number in the **Harmonics list** field. Separate multiple entries with the semicolon (**;**). In the example below the 1st, 2nd, 3rd, 4th and 5thorders are selected. If the extracted order falls between discrete order resolution steps, the closest fitting resolution will be taken, so if the resolution is 1st order and 1.8 is extracted, 2ndorder will be used.

FFT window & Amplitude define the shape and amplitude of your measured FFT's. You can learn more about FFT windowing in the FFT course.

Data averaging can be done in two ways:

None	(Center of the class is taken. For example, if the class is defined from 125 RPM to 175 RPM (delta RPM is 50), the calculations will be done only at the lines (number of lines is calculated from maximum order and order resolution) around 150 RPM.)
Average between classes	(it takes consecutive FFTs through the class and averages them.)

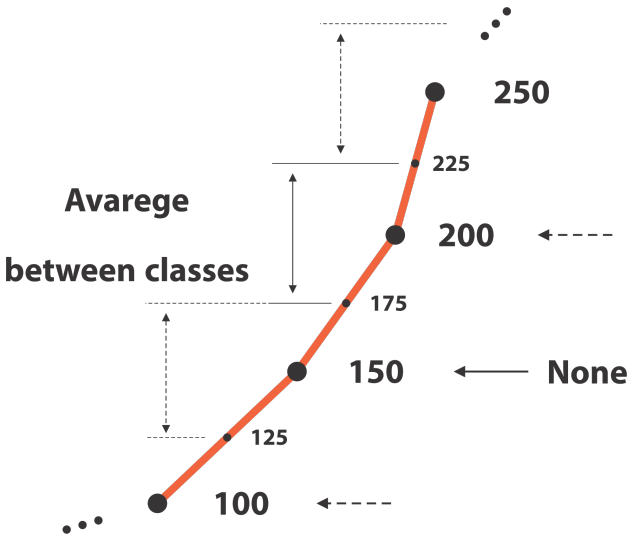


Image 24: Data averaging types

Update criteria is applied to array channels (Order domain harmonics, Order waterfall vs. RPM, FFT waterfall vs. RPM). It defines if the waterfall should be updated:

Always	if you have more run-up or coast-downs, the new value will be written in an element of an array
Only first time	if you have more run-up or coast-downs, only the first run will be used
Average	if you have more run-up or coast-downs, the element of an array will be calculated as an average between the old and new samples

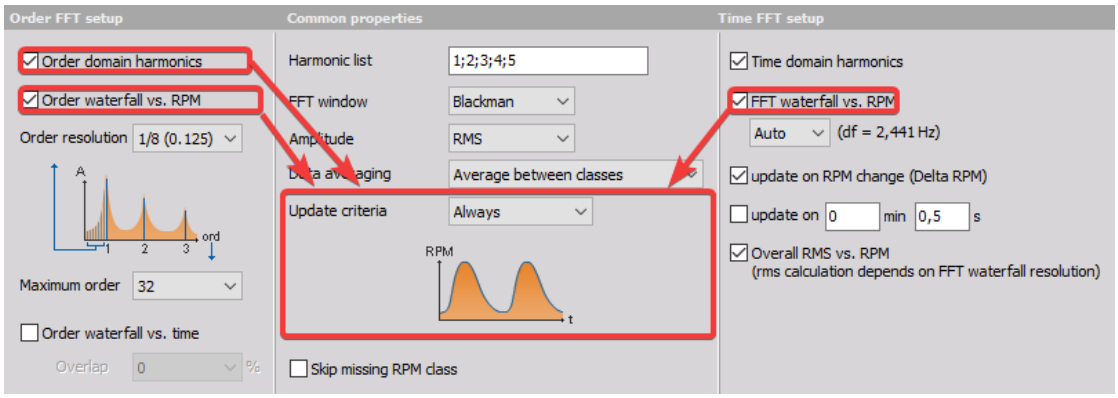


Image 25: Update criteria

With the **Order FFT setup** channels, the update is done if the RPM change is bigger than the **Delta RPM** or if the maximum time limit in **Update on time** is reached.

Sometimes it is also necessary that the order tracking calculation is done in a fixed time interval, independent of the rpm, e.g. when a car is driving a defined track or a machine is operated and observed during a working cycle. If this is needed, **update on** must be checked, so the calculation will be updated independently from the rpm every 0.5 sec (overwrites frequency limits - delta RPM setting). This applies only to the **Time domain harmonics** and **Order domain harmonics** channels that you entered into the **Harmonic list**.

Order FFT setup

In the **Order FFT setup**, you can enable or disable different options to tailor the acquisition to your needs.

Order domain harmonics	enable or disable harmonic channels, that are created from your entry in **Harmonic list** under **Common properties**, and are displayed in 2D Graph
Order FFT vs RPM	create channels that are used by 3D graph for the display of Orders in relation to Speed
Order resolution	define the number of lines between two orders
Maximum order	sets the maximum displayed order (To set the **Maximum order to analyse** go to Options / Settings / Extensions / Order tracking)
Order waterfall vs. time	create an order waterfall that is updating in regards to **Time FFT setup**'s **Update on time** field

Depending on the Upper RPM limit and the Maximum order used, the OT module will output a warning if the used sample rate is too low.

For example, set Upper RPM limit at 6000 and Maximum order at 64. The minimum required sample rate is calculated like this:

First-order at max speed: 6000 rpm / 60 = 100 Hz; so the highest order will be 100Hz * 64 = 6400 Hz. Because of FFT analysis, the sampling frequency must be doubled to fulfil the Nyquist criteria: 2 * 6400 = 12800 Hz.

> In an FFT, if the line resolution is 0.5 Hz, the required data window must be 2s. The same is true for the ordered resolution: If the resolution is set to 0,25 orders, 4 revolutions are required for one data block.

The higher the required order resolution, the more slowly the rpm must change.

Order domain harmonics

Order domain harmonics are **complex channels** displayed on the **2D graph**. In the **Harmonic list** section, you define which harmonics you want to extract.

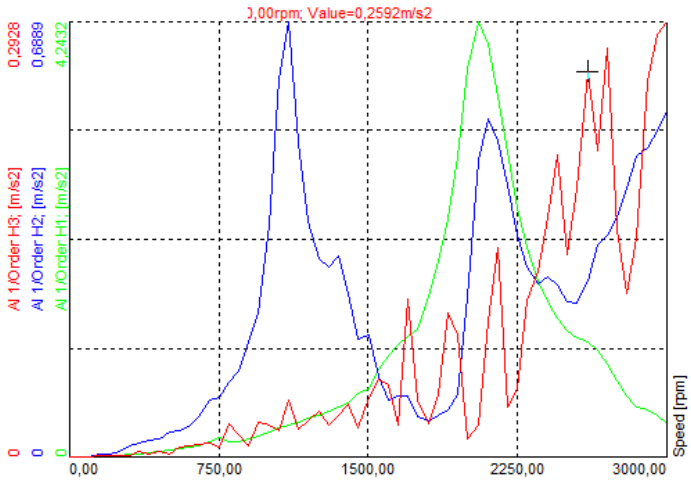


Image 26: Extracted Order domain harmonics

Order waterfall vs. RPM

Order waterfall vs. RPM monitors current values of orders. You define the order resolution and the maximum order that will be shown on a 3D

graph.

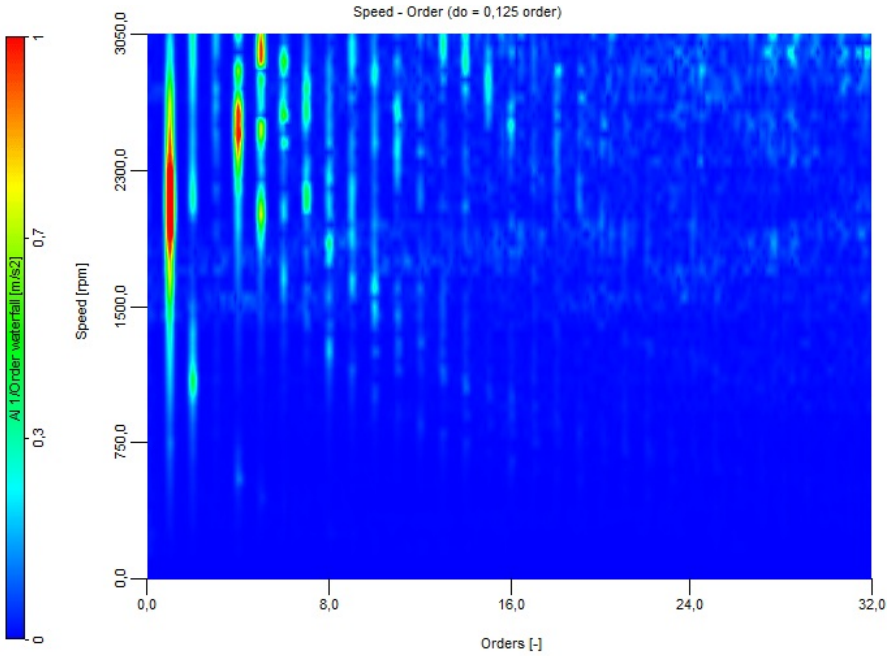


Image 27: Order waterfall vs. RPM

Order waterfall vs. time

Order waterfall vs. time monitors orders through time and not only the current values. The channel is updated when every new FFT is being calculated.

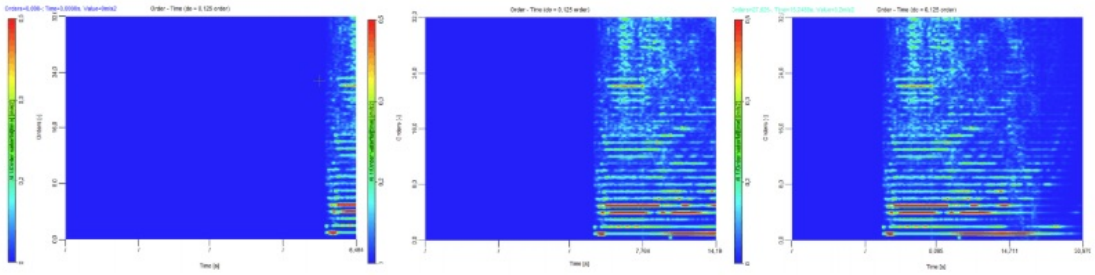


Image 28: Order waterfall vs. time

Output extracted harmonics as channels

This will extract specific orders from the order waterfall plot to be used as channels. So it is possible to draw a specific order over time, or over engine speed.

To extract the orders simply enter the wanted number in the **Harmonics list** field. Separate multiple entries with the semicolon "**;**". For example, if you wish to extract 1st, 2nd and 3rd, 4th and 5th order, simply **input 1;2;3;4;5** and press **Enter**. If the extracted order falls between discrete order resolution steps, the closest fitting resolution will be taken.

Time domain and order domain harmonics are both complex channels. To get the **amplitude** from the complex number, use the **ABS** function in **Math module**.

```
abs('AI 1/Order H1')
```

To get the **phase angles** from complex numbers use the **ANGLE** function in mathmodule (only available when using RPM sensor with zero-angle information).

```
angle('AI 1/Order H1')
```

To get the **real** and **imaginary** part as separate channels out of the complex number, use two math formulas:

```
Real = real('acc/Time domain'[0])
```

```
Imaginary = imag('acc/Time domain'[0])
```

In the example above, the index [0] will show 1st harmonic, index [1] will show 2nd, and [2] the 3rd harmonic.

Extracting the interharmonics

In order tracking module there is an option to extract interharmonics (half-orders). Enter the number in the harmonic list section. Use "**.**" for separation. For example, **0.5;1;3;**etc..

Warning: Interharmonic phase can not be calculated!

Order domain harmonics and interharmonics are complex channels displayed on the 2D graph.

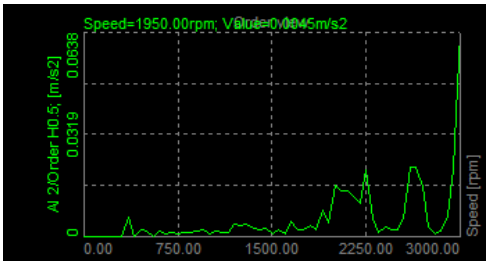


Image 29: Extracted 0,5th Harmonic

WARNING: Only the amplitude will be calculated for the interharmonics (0.5; 1.5; ...) and not the phase. The phase can only be calculated for the whole harmonics (1^{st}, 2^{nd}, ...). The phase is turning on the interharmonics because they are not integer multipliers of first order and phase gets to be calculated in different places in each period (with normal harmonics this calculation is always on the same spot).

Time FFT setup

The order tracking module creates a waterfall plot out of the rpm change. So every time the RPM changes for the defined **Delta RPM**, an FFT is calculated for that data block and shown in the Time FFT diagram

The FFT resolution and data block length is per default automatically calculated out of sampling rate, order resolution and maximum order.

This data block is fed into a special mathematic algorithm, which resamples the data so that we get exactly 2x values during one revolution. Out of that, we can get the order and phase spectrum without any leakage of FFT values. So FFT lines (orders) will have the exact amplitude (no smearing) and phase, almost no matter how fast we change the engine speed.

Time-domain harmonics

This is a complex output channel showing the amplitude of harmonics in a time domain. In the harmonics list section, you define the harmonics that you want to extract.

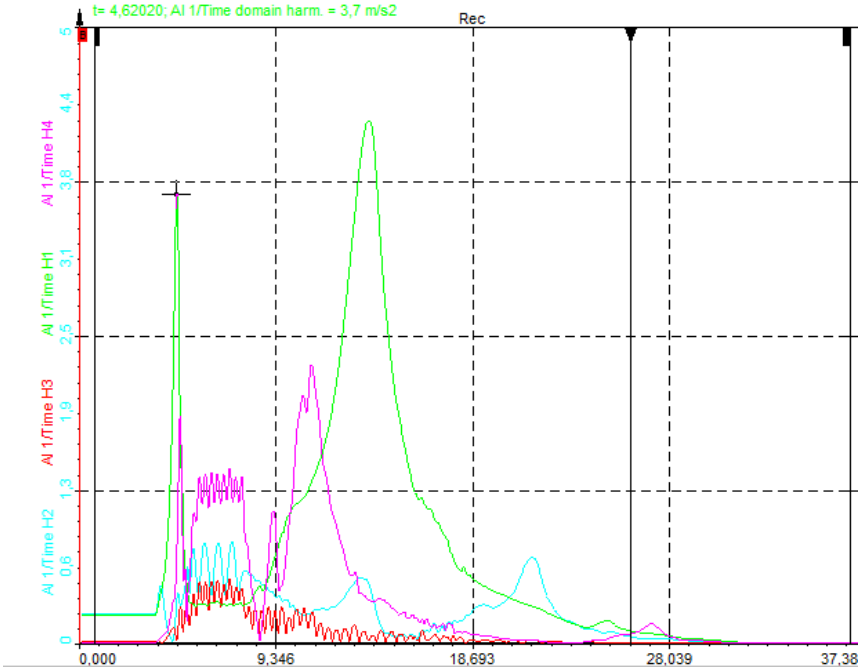


Image 30: Amplitudes of harmonics in time domain

FFT waterfall vs. RPM

If **FFT waterfall vs. RPM** is enabled, the *Time FFT waterfall diagram* will have a defined number of lines for one RPM shot. The resolution is calculated from the max. order, sample rate and order FFT size. For better understanding, the delta frequency is also shown.

By default, the resolution is set to **Auto**. You can manually change the FFT resolution in the FFT waterfall diagram by selecting a value from the drop-down menu. The values are:

- **128**
- **256**
- **512**
- **1024**
- **2048**
- **4096**
- **8192**
- **16384**

Example of difference in calculated and displayed data:

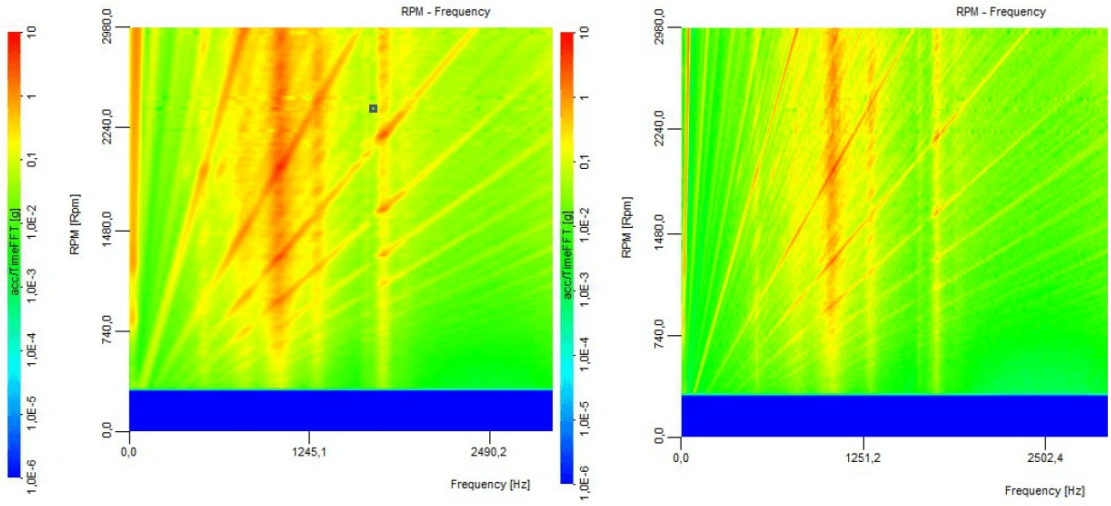


Image 31: Difference between left: Df = 24 Hz; right: Df = 6 Hz

The second picture shows much sharper lines and separates much clearer into single frequencies.

Overall RMS vs. RPM

RMS calculation depends on FFT waterfall resolution

This channel shows the overall RMS amplitude over the range of RPMs.

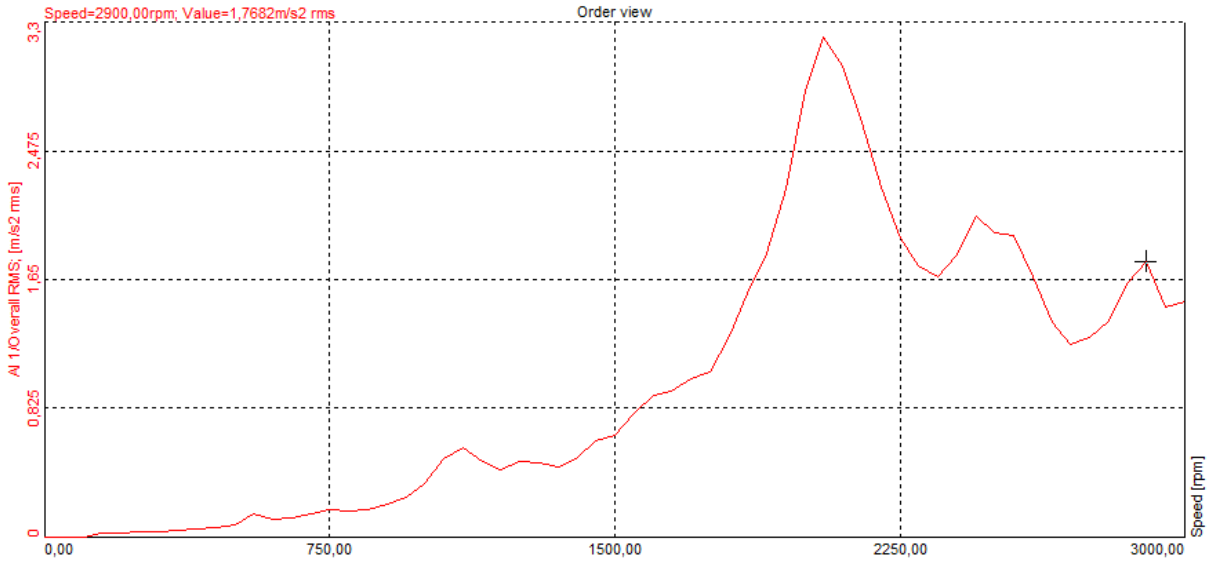


Image 32: RMS of signal over different RPM

Extract specific order

Order domain harmonics are extracted in "orders over RPM", shown on a 2D graph.

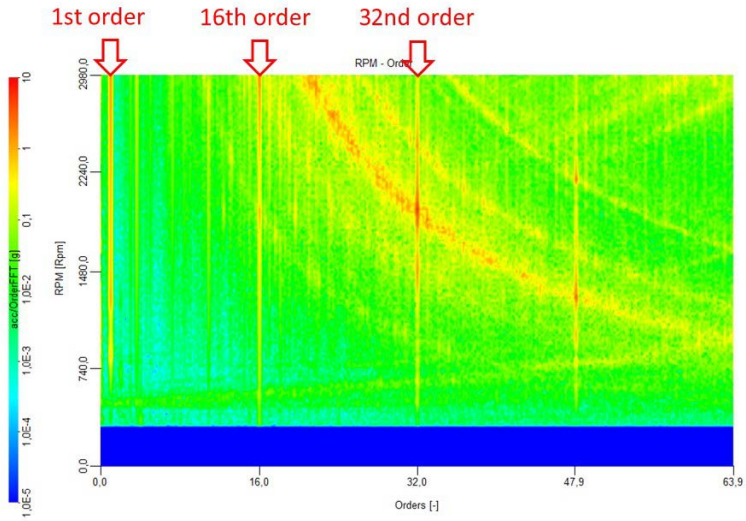


Image 33: Marked 1st, 16th and 32nd harmonic

The graph above shows a vibration spectrum of an electrical scooter motor, standing on rubber foam. The three major orders are marked (1st, 16th and 32th). It is also possible to extract them and see the amplitudes and phases over rpm.

This is the old way but still applies, especially if you want to monitor the behaviour of extracted order over the whole time interval (Order domain harmonic values get overwritten, when we hit RPM value that was already used).

Please use the XY recorder for displaying the extracted data:



Image 34: XY recorder Icon

First, pick the OT_Frequency channel from the channel list (x-axis) on the right side, then assign the abs('signal/Time domain'[0]) channel (y-axis).

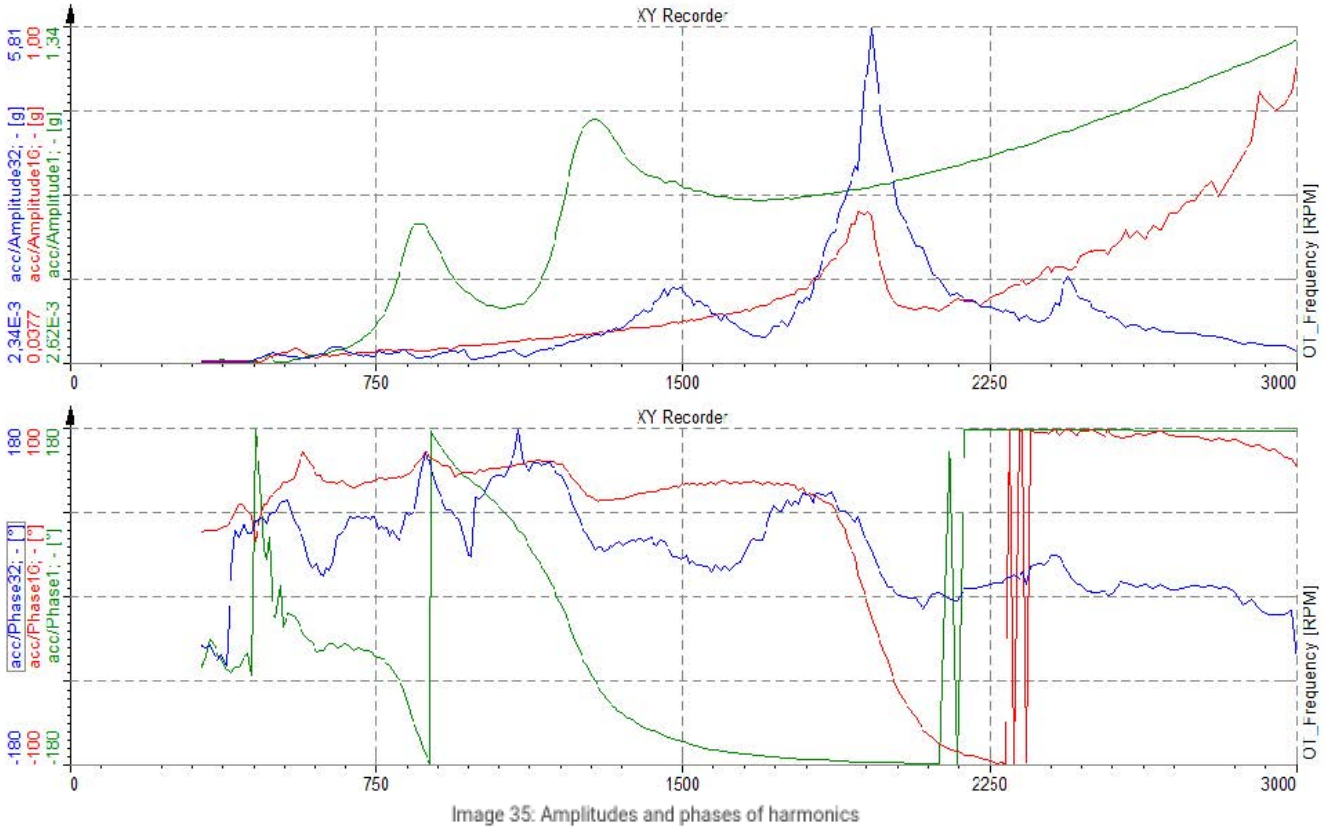


Image 35: Amplitudes and phases of harmonics

Measurement and visualization

As the order tracking is done during a run up or coast down, the visualisation instruments show the vibration spectrum (and the orders) over RPM and frequency. Single order lines can additionally be extracted.

Automatic display mode

With the order tracking module enabled when you start the measurement, Dewesoft X will automatically generate a predefined display setup showing the major signals for a quick start.

In the picture below, the automatic display configuration is shown. The visual controls in the bottom left of the screen are 2D graphs, which display the selected channels in different **Complex presentations**. In this example, you can see the Magnitude of Overall RMS besides the 1st & 2nd extracted harmonic.

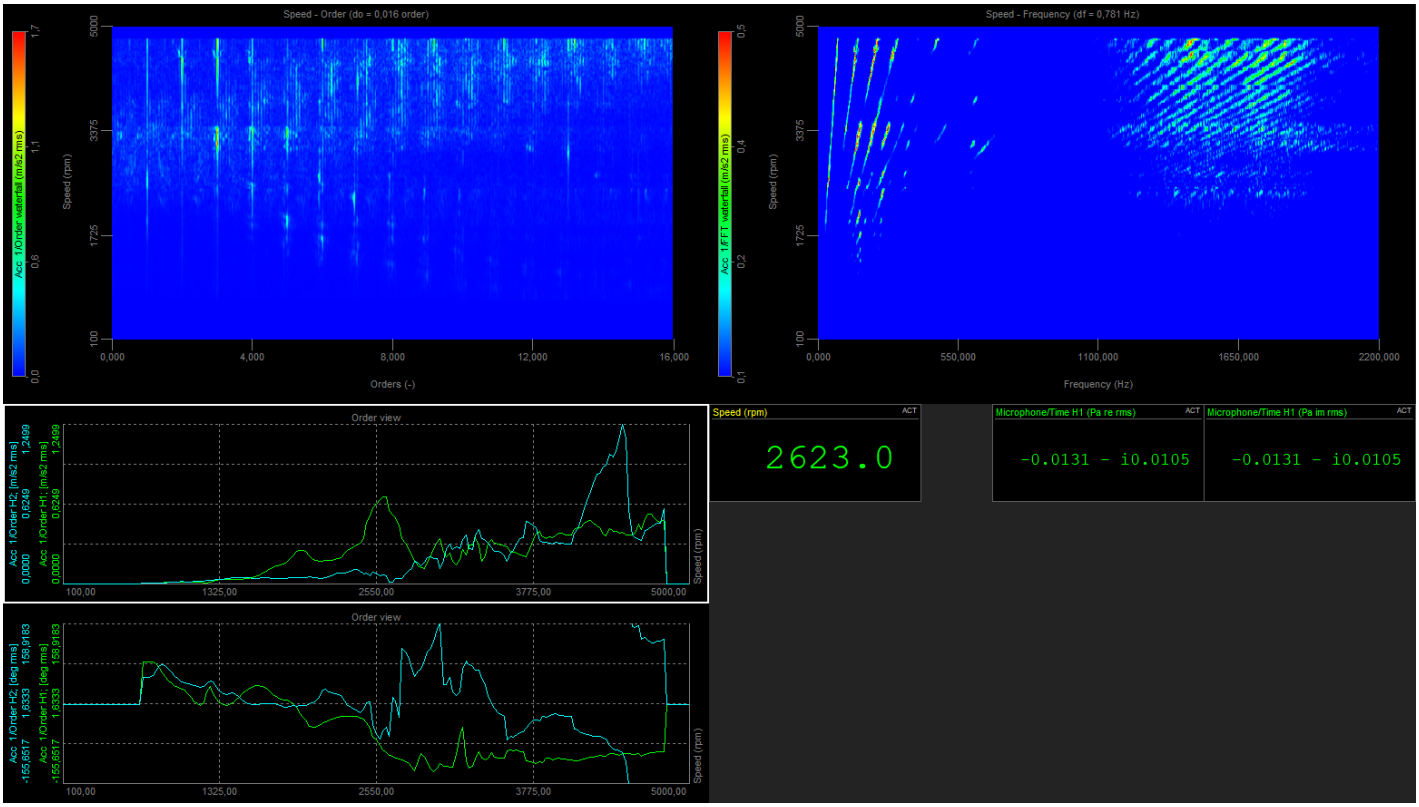


Image 36: Predefined Order tracking display

The handling of all visuals follows the same concept. For the selected visuals, the properties are shown on the left side. The channel selector for this visual is shown on the right side. Only channel types suitable for the selected visual are shown. E.g. you can't select statistic channels of a visual holding angle based data. Already selected are shown in bold.

You can use **Search** for quickly finding the wanted channels on top of the channel list.

Image 37: Channel list search bar

Customizing display

Dewesoft X allows a completely flexible arrangement of the displays. The major displays for order tracking measurement are described below.

The most important instrument for order tracking is the 3D graph.

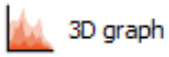


Image 38: 3D graph Icon

FFT waterfall vs. RPM

When you add it in design mode and assign the **channel/FFT waterfall** from the channel list to it you will get the FFT waterfall vs. RPM.

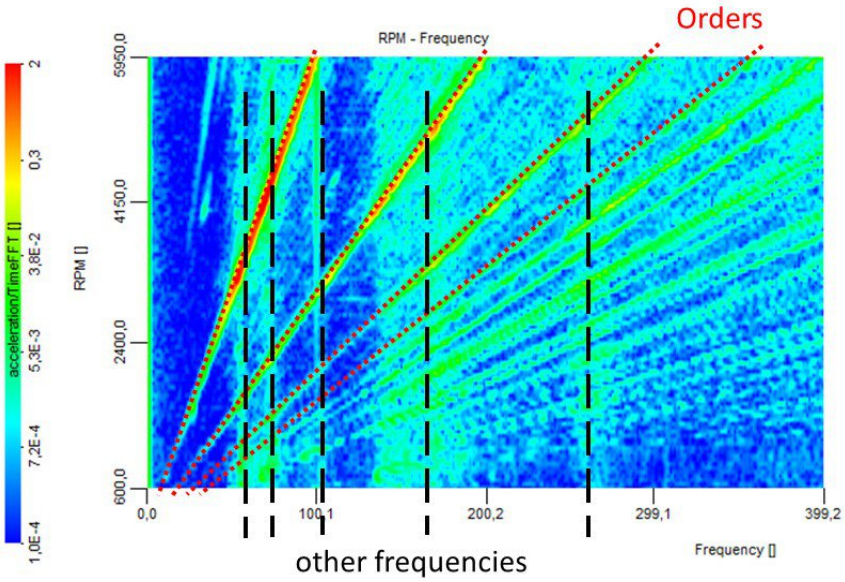


Image 39: Orders and resonant frequencies in FFT waterfall vs. RPM

The waterfall plot shows a number of FFTs plotted across the RPM range (y-axis), where the vibration amplitude is shown as color (up-direction in 3D mode).

With this instrument, you can separate the spectrum into frequencies related to RPM (orders) and other frequencies (e.g. resonances of the mechanical structure, noise from the electrical grid, ...).

The 3D FFT instrument is updated in real-time during measurement, it will grow during run-up / coast-down, already showing the end result.

Order FFT waterfall

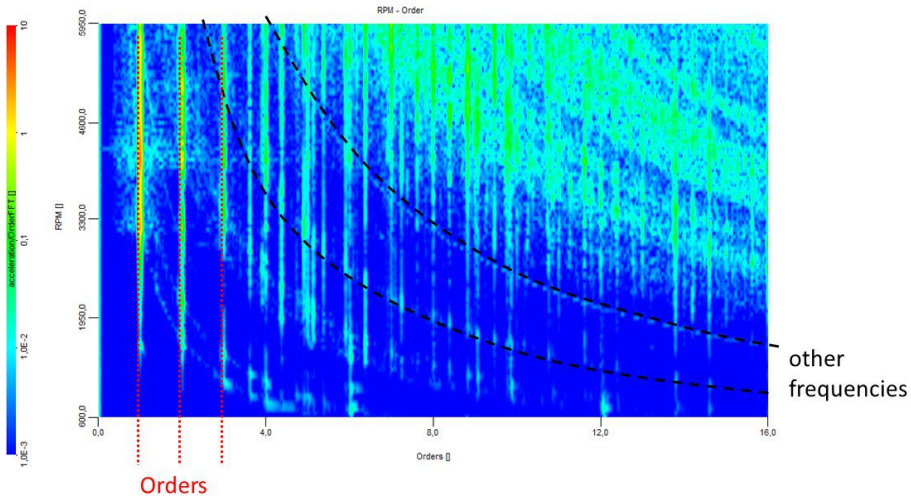


Image 40: Orders and resonant frequencies in Order FFT waterfall vs. RPM

With the 3D graph instrument, the **order FFT** can also be shown.

Orders are plot versus RPM. Again, the colour shows the vibration amplitude.

The straight lines parallel to the y-axis are the orders. This is very helpful because the frequencies of the orders change with RPM, and sometimes it is difficult to trace them.

Example: frequency change of the first order with rpm:

- 1st order at 600 rpm = 600/60 = 10 Hz
- 1st order at 4600 rpm = 4600/60 = 76,7 Hz

Below you see the comparison: Time FFT (left) and Order FFT (right). The straight 100 Hz noise line in the Time FFT appears as a curve in the Order FFT; marked with a red dotted line in the two graphs.

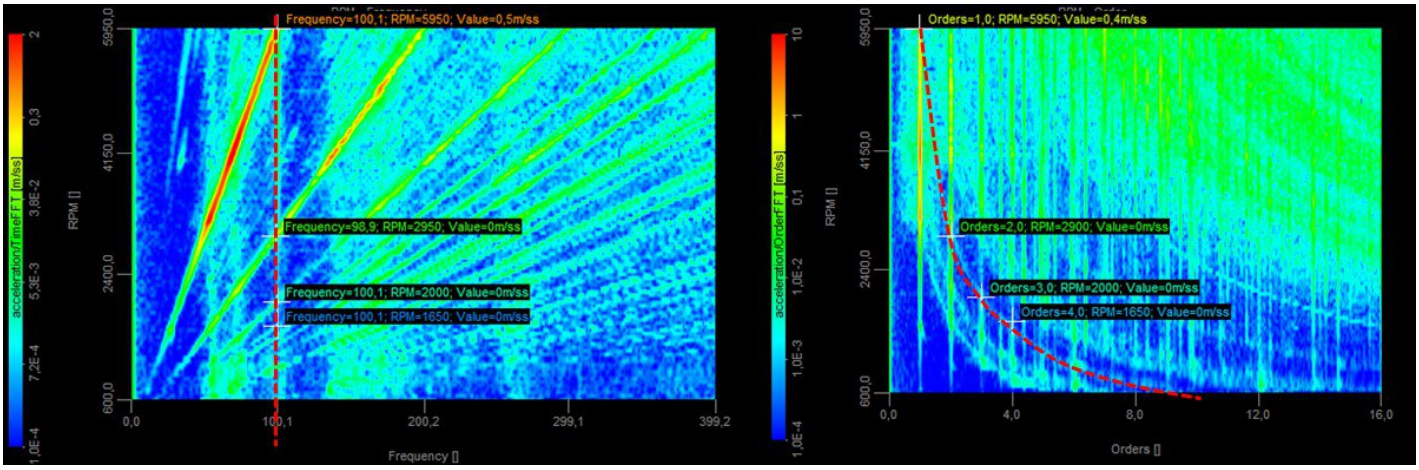


Image 41: Comparison: Time FFT (left) and Order FFT (right)

Polar diagram / Nyquist plot

For this functionality, you have to **enable** the **Time-domain harmonics** checkbox in the **Order Tracking setup**. It is also possible to draw the Polar diagram with Order domain harmonics.

In the example with the scooter motor, the strongest orders are relatively high, so we selected 1; 16; 32 in the **Harmonic list**.

The Complex output (Re + i * Im) has to be split up into real and imaginary part using **Math**. To do this create a **new formula** and **add** one the beginning **real() and imag()** to the signal/Complex channel. This can also be done offline on the data file, after the measurement. Go to Recalculate and take a look at the Math preview again.

```
real('acc/Complex')
```

An array will be created, which is basically the four channels re1, re16, re32 and re48 combined into one multidimensional channel. If we want to access the components, we simply add [i], where i is the index {0,1,2,3} representing the order {1,16,32,48} in our example. So real('signal/Complex'[0]) will give the Real part of the 1st order.

```
real('acc/Complex'[0])
```

Then do the same for the imaginary part with imag('signal/Complex'[0]) :

```
imag('acc/Complex'[0])
```

Then take the XY recorder and first assign the Real1 channel and then the Imag1 channel to it.

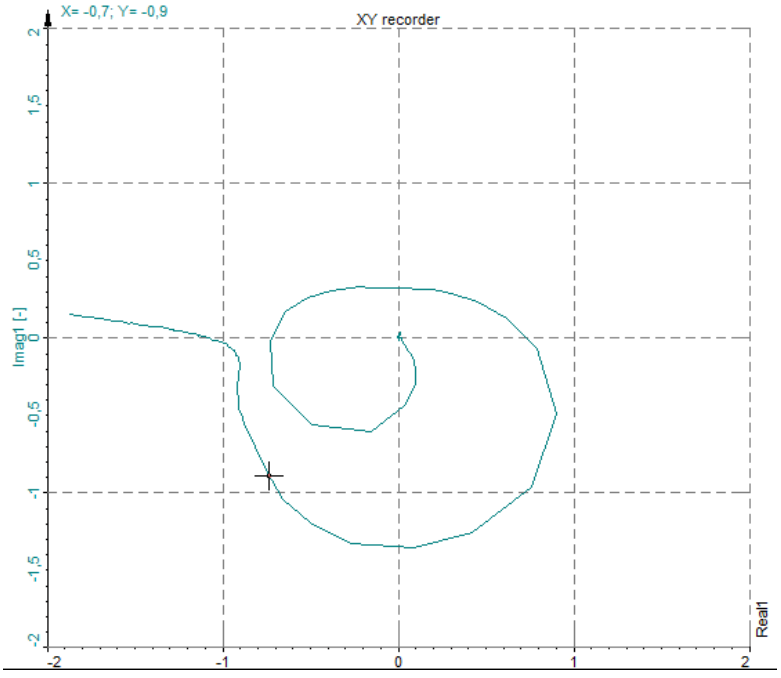


Image 42: XY display of Real and Imaginary values

The x-axis and y-axis are manually scaled to the same min/max value to show the angle proportion correctly.

On the **left side**, in the **properties**, you can select if you want to **display all data**, **only the current data**, or over a **specified window** with the Pre time limit option.

3D FFT cut

Take a look at the Time FFT waterfall again. As discussed before, it consists of a lot of FFT's (one for each delta RPM) and it might be interesting to extract a single FFT for a user-defined RPM.

Open a data file, go to **design mode** and **right-click** on the 3D FFT instrument, select **Info channels**.

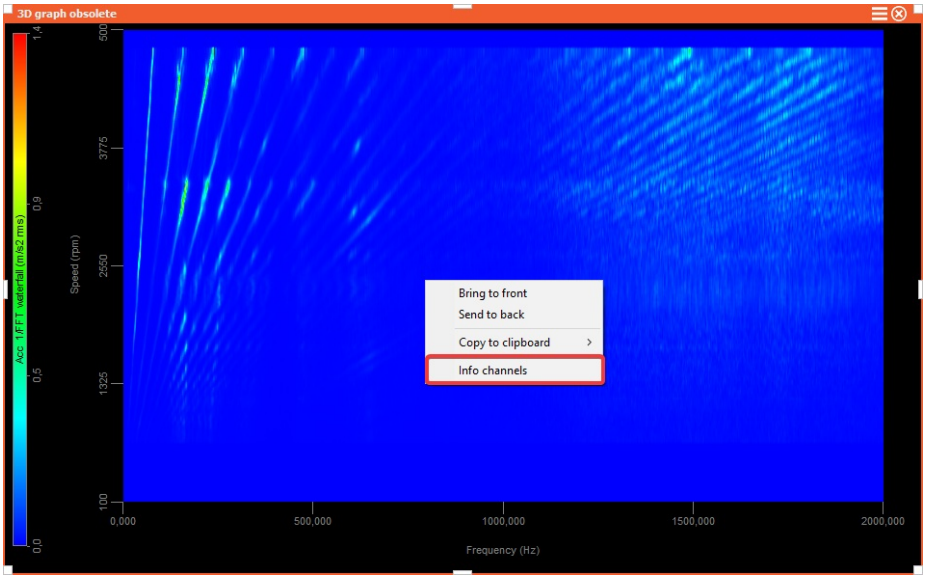


Image 43: How to access Info channels in 3D graph

Enable the channels X cut and Y cut.

Info channels

Enabled	Name	Count	Description
on	%INPUT%/X cut	1 per input	X cut
on	%INPUT%/Y cut	1 per input	Y cut

Image 44: Info channels menu

Then add a 2D graph from the instrument toolbar.

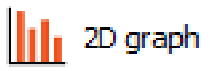


Image 45: 2D graph Icon

Assign the channel **signal/TimeFFT/X cut** or **signal/TimeFFT/Y cut** to it.

Exit the design mode. Then **click** on the 3D graph instrument on the interesting point, **where you want to cut the FFT**.

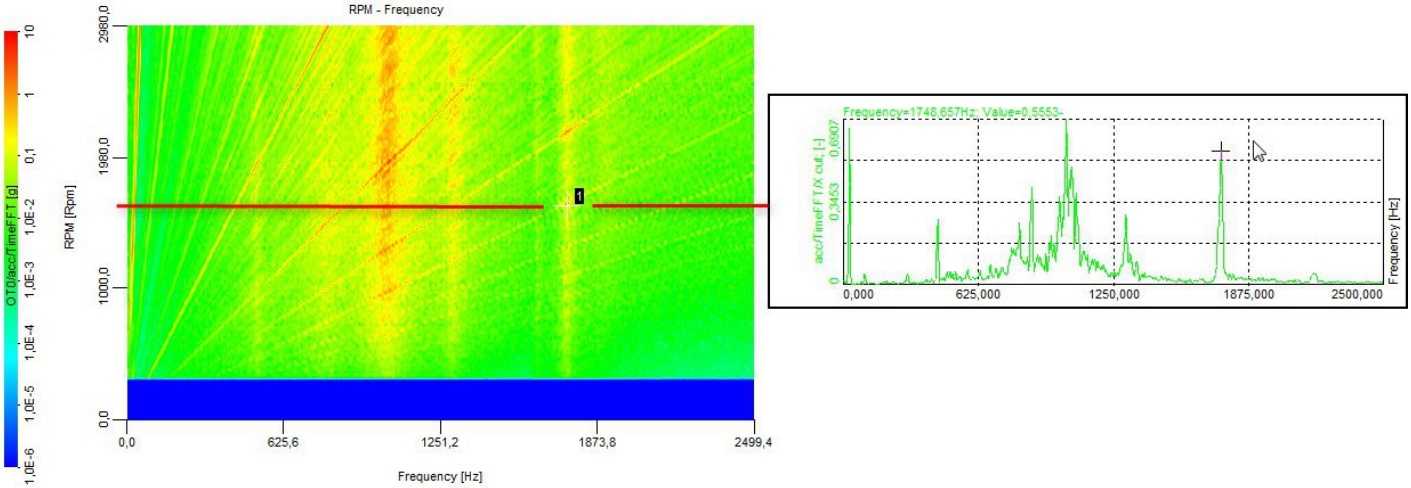


Image 46: Example of an X cut at position "1"

FFT peak calculation

One of the standard measurements is the run-up of the machine and then a calculation of the max amplitude over the FFT.

Add an **FFT math** from the Math module.



Image 47: FFT math Icon

Then select the **input** channel, for example, select an acceleration sensor. Set the

- **Output spectrums** "**output**" to Amplitude,
- **Calculation type** to Overall (Averaged) and **Averaging type** Peak.

You can do the **FFT math** in Measure mode or recalculate in Analyse mode

Add a **2D graph** from Widgets and assign the *Channel*/**AmplFFT.**

In 2D graph **display options**, type of Y-axis can be set to logarithmic.

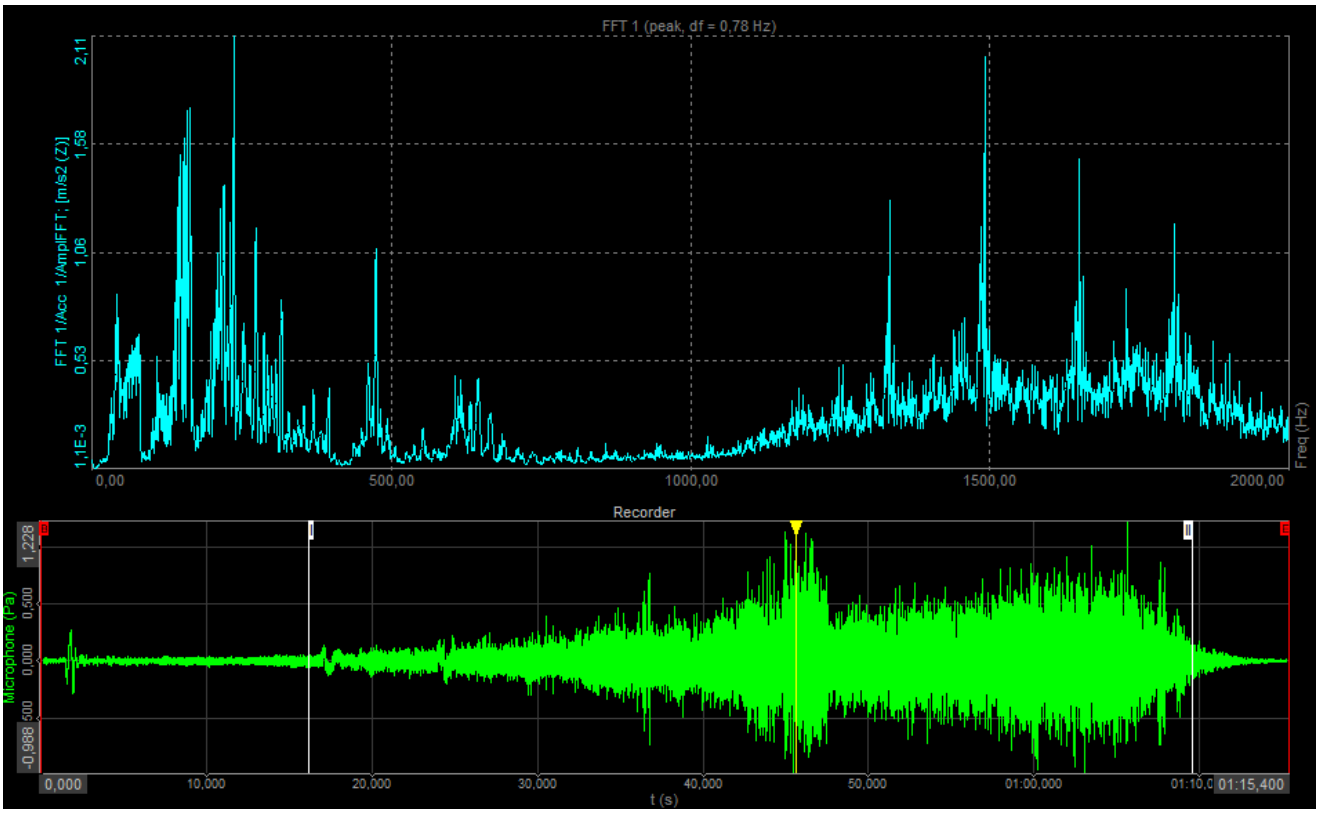


Image 48: Selecting a specific time frame for FFT recalculation

In the recorder you can select a specific section of data-file, this will perform the **PeakFFT** over a specific RPM range.

Campbell plot

You can also display TimeFFT or Order FFT on Campbell plot.

Click on Design button and add Campbell plot with clicking on the icon shown below.



Image 49: Campbell plot icon

If you compare the ordinary 3D graph and Campbell plot, you quickly see that the Campbell plot can be a powerful tool for Analysis.

Also, order FFT can be displayed in Campbell plot.

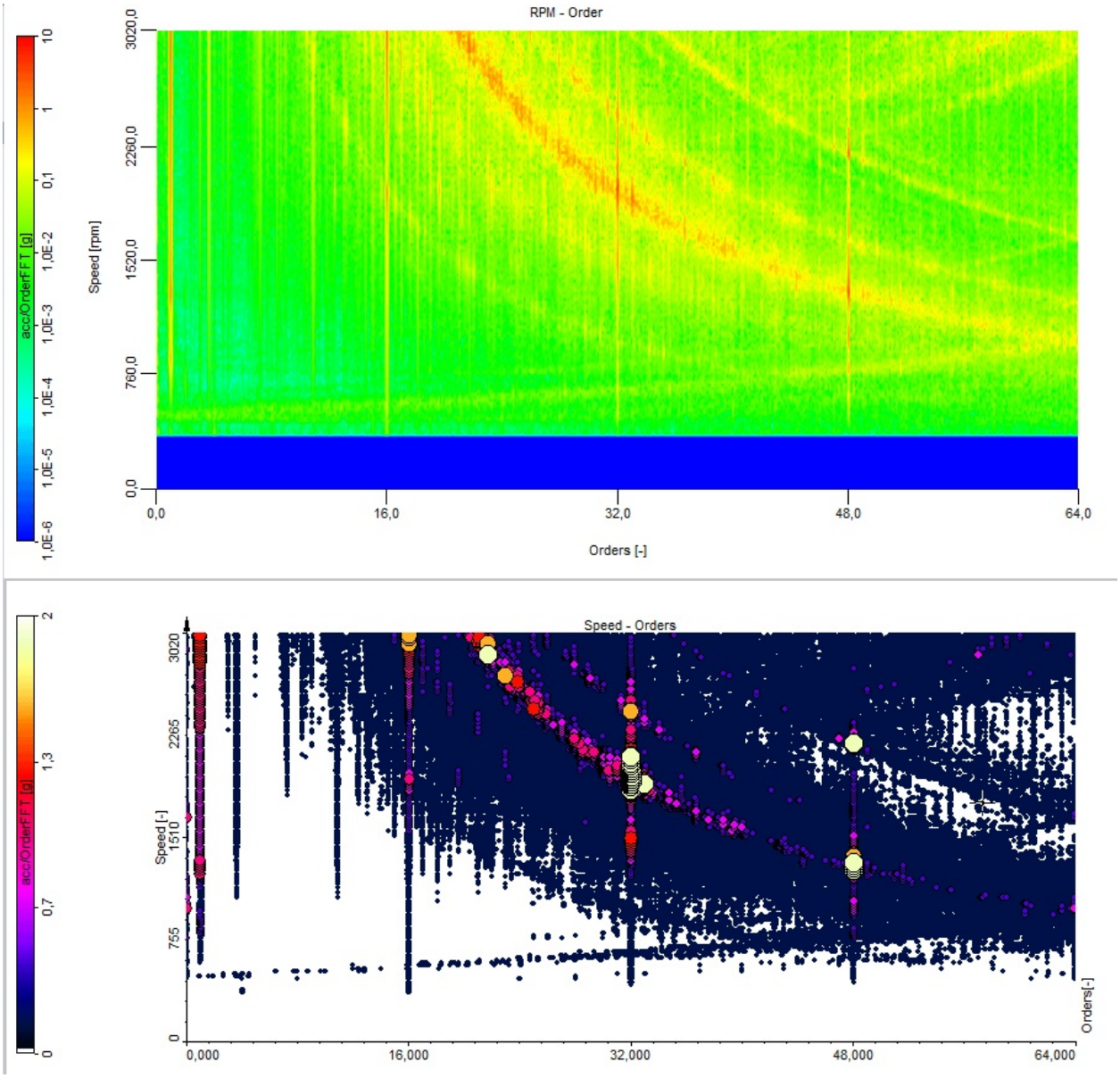


Image 51: Comparison of the Order FFT waterfall vs. RPM in 3D graph and Campbell plot

Options

Campbell plot presents multiple options to manipulate its design.

- **Cutoff**

- **Levels**
- **High-value size**
- **Low-value size**
- **Palette**
- **Circle style**
- **Projections**
- **Interaction**

Cutoff

The cutoff is given in per cent [%]. It determines the size of the portion that will be cut out from the range of shown values. Diagram's scale shows which values will not be shown by hiding the scale's colour map. Next picture shows an example with no cutoff (0%) on the left side and on the right side cutoff was equal to 30%. Scale's colour maps are changed accordingly.

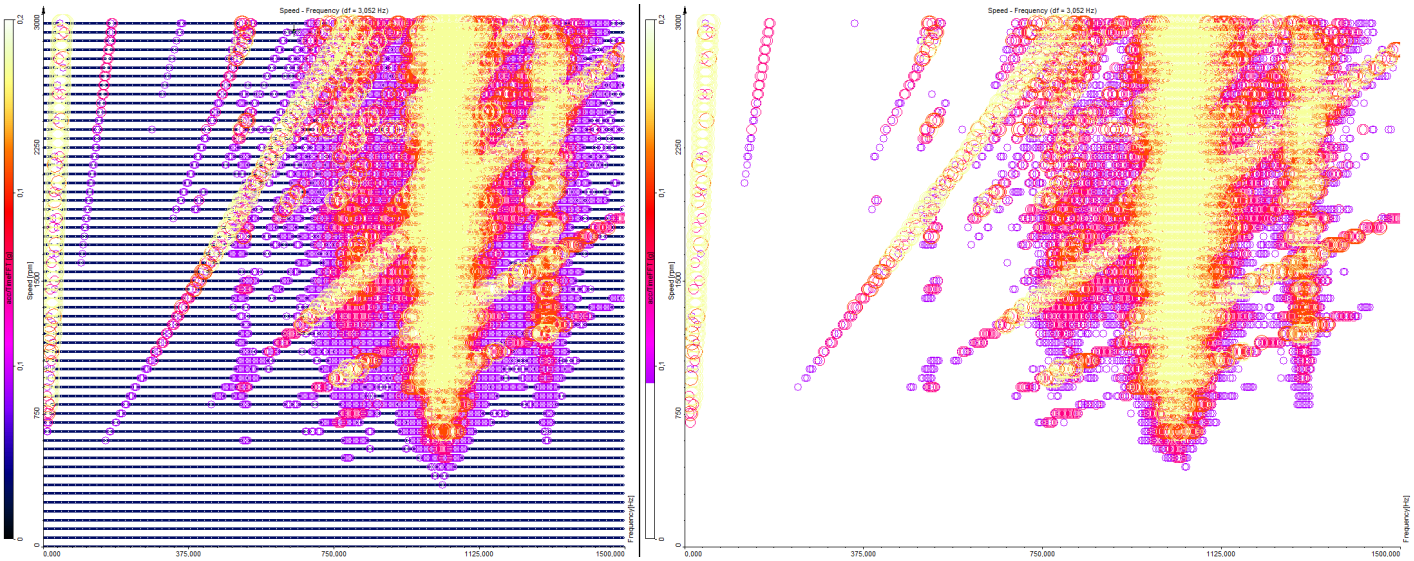


Image 52: Campbell plot cutoff level comparison, Left 0% and Right 30%

NOTE: By clicking on the diagram and hovering over the scale with your mouse, you can easily define your Cutoff by scrolling up and down.

High and low-value amplitudes correspond to the diameters of circles from largest to smallest. Diameters of circles from levels in between increase linearly from lowest to highest diameter with respect to the number of levels. Each level has its own diameter.

Levels

Minimal and maximal value on the diagram's scale (on the left side of Campbell plot visual control) represents the range of values which will be segmented into levels. Values, bigger than maximal value, belong to the highest level and values, smaller than minimal values fall into the lowest level. On the picture below you can see an example, how values range is segmented into levels, where a number of levels is set to 5.



Image 53:
Levels bar

The number of levels can be changed within Levels edit field on the Options tab.

Palette

Scale's colour map can be generated from different palettes (Palette drop-down window on left). Below you can see examples of all of them;

- **Rainbow** (warm),
- **Rainbow**,
- **Grayscale**
- **single colour**, (colour from the channel on the diagram).

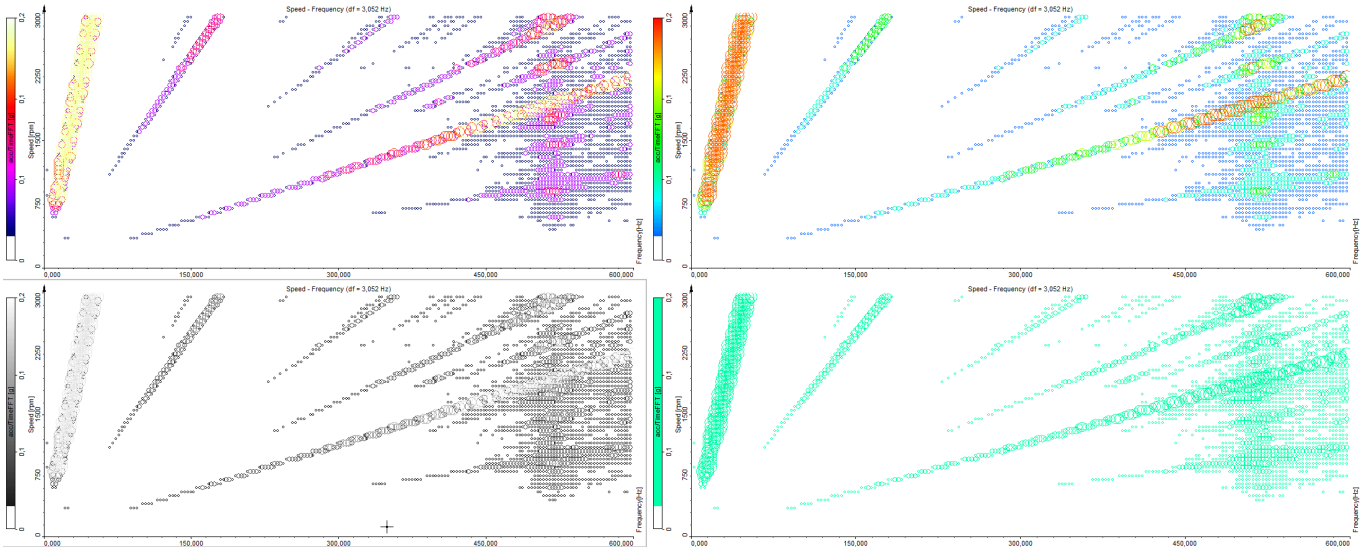


Image 54: Comparison of different palette options for Campbell plot

Circle style

There are two possible circle styles; **outline** (by default) and **fill**. On the left "filled" circle style is shown and on the right only "outlined" circle style is displayed.

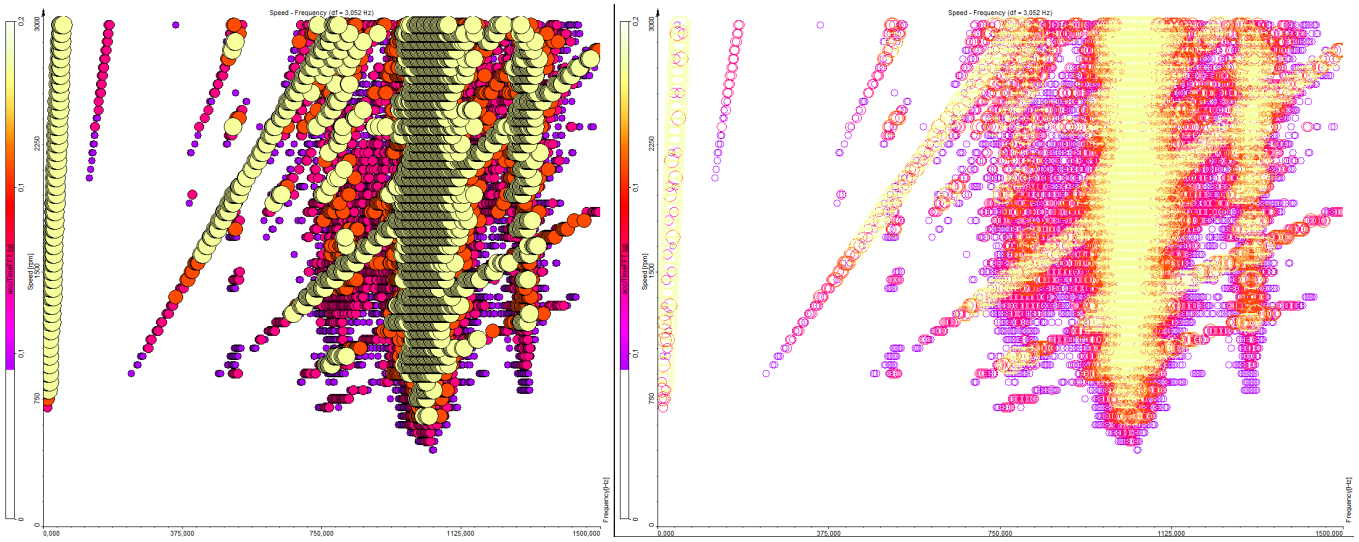


Image 55: Left "filled" and right "outlined" circle styles are displayed.

Projections

Campbell plot lets you choose between XY and YX projections. XY has x-axis horizontal and y-axis vertical, YX projection has it the other way around; x vertical and y horizontal.

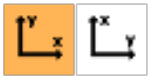


Image 56: Different projections

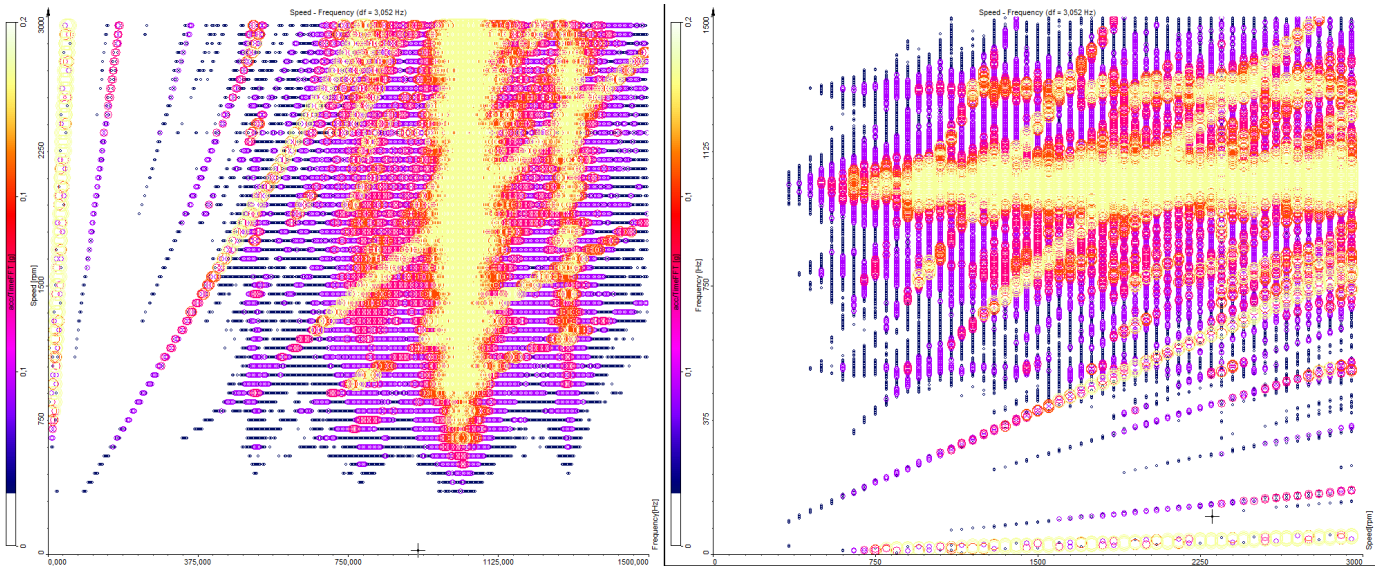


Image 57: XY projection on left, YX projection on the right

Interaction

Selection marker shows you the value of the area where your mouse cursor is currently positioned on the diagram. Value is shown in the upper left

corner of visual control.

Free marker allows you to mark the position with one left click of the mouse on the wanted area. You cannot click on the area where there are no values (cut out levels). Little cross will be drawn, to show marker's position with its index written on the side.

Show marker table when selected a table with collected marker values will appear. It displays values of free markers and also lets you remove each of them.

Show marker table only works with Free markers
Show marker values if checked, the value on the marker will be shown instead of its index.

Orbit graph

In this example, a visualization of the movement of a rotating disc will be done. To have a high angular resolution you typically use an encoder with 1024 pulses per revolution. A 2-axis acceleration sensor is mounted on the metal frame holding the motor. The axis orientation is shown as below.

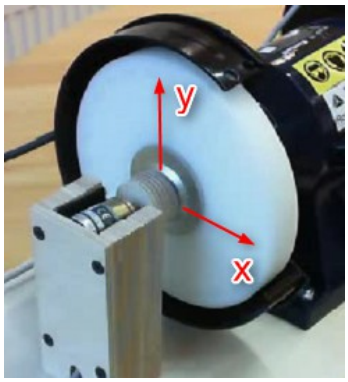


Image 58: Grinding wheel on a bench grinder

The output of the sensor is an acceleration in m/sÂ². If you use double integration on it, you can calculate the displacement in Î¼m. This can be done using **Time integration, derivation** in Dewesoft X mathematics.

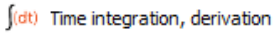


Image 59: Time integration, derivation math Icon

You have to carefully choose the **Order** and **Low**-pass frequency, not to create an unwanted and unstable output signal. To determine the filter frequency, make an FFT spectrum on the acceleration sensor and look for the lowest dominant frequency. 4th order 4 Hz is a good starting point (signals below 4Hz * 60 = 240 rpm will be cut). If you use lower frequencies / higher orders the filter can start slowly bouncing due to integral math DC output.

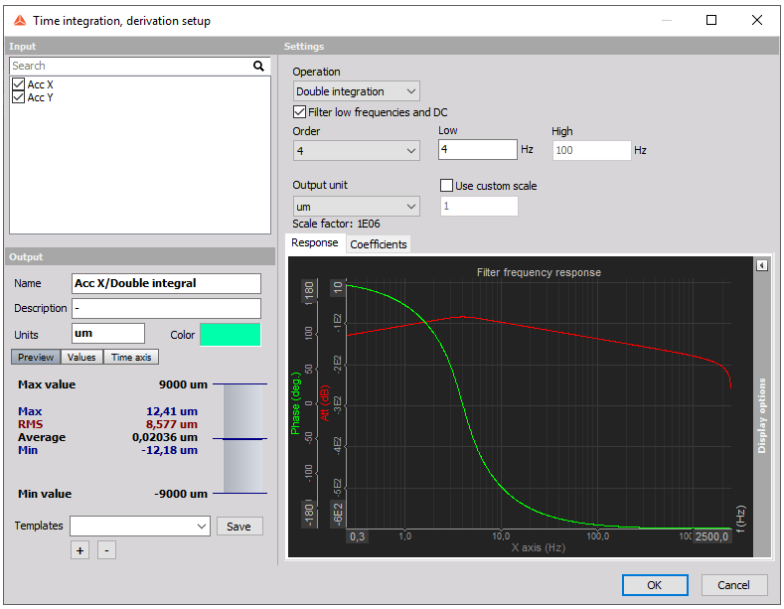


Image 60: Time integration, derivation math setup

The widget that will display the movement of the shaft is **Orbit**, located under **Machinery diagnostics**.

First assign **x**, then **y** displacement channel. Both axes are scaled with the same min/max values automatically.

The orientation of the sensors can be modified on the left side, and also the displayed time can be selected. Under **Angle** define the angle of your **First channel** "X" sensor position and under **Second channel** "Y" sensor's angle.

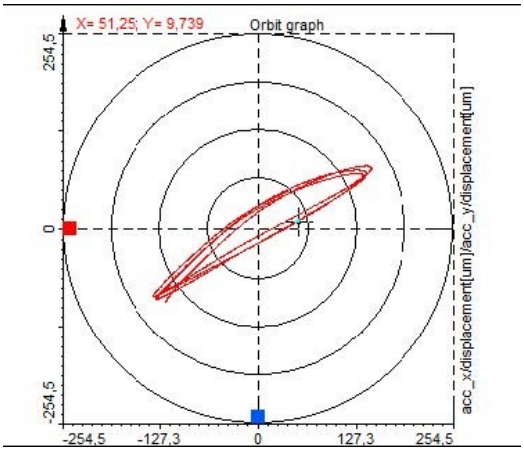


Image 61: Orbit display

Analyse and export

In the Analyse mode, Dewesoft X provides data review, modifying or adding Math-Modules and printing the complete screen for generating your report as well. Similar to the Measurement mode you can modify or add new Visuals or Displays. All these modifications can be stored in the data file with Store Settings and Events. This display layout and formulas can also be loaded on other data files with Load Display & Math Setup or with the multi-file operation Apply action.

Export of complex data

Go to the **Export** section to access different types of exporting options. Select **File export** and under **Data presentation** you will see the Real, Imag, Ampl and Phase options. Select **Real** and **Imag**.

Select **Yes** in the **Exported** column besides the **Complex Data type** channel you want to export.

If you additionally select other channels, they will not be affected. This setting is only applied to the Complex dataset.

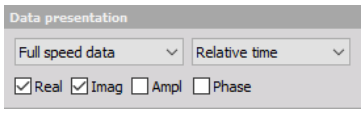


Image 62: Export data type selection

For each order, we selected for calculation in the order tracking setup (1st, 16th, 32nd, 48th) two columns (Real, Imag) are exported.

	A	B	C	D	E	F	G	H	I
1	Time	OT0/acc/Complex1_Real	OT0/acc/Complex16_Real	OT0/acc/Complex32_Real	OT0/acc/Complex48_Real	OT0/acc/Complex1_Imag	OT0/acc/Complex16_Imag	OT0/acc/Complex32_Imag	OT0/acc/Complex48_Imag
2	s	g	g	g	g	g	g	g	g
3	0,3264	-1,8924294	-1,8670999	-0,59492481	0,6226669	0,14801131	1,7072728	0,94815034	0,06560488
4	0,75022	-1,8914028	-1,8645577	-0,55500567	0,59901708	0,14439532	1,8958366	0,88525283	-0,072931036
5	1,25028	-1,8891592	-1,8219287	-0,62545186	0,65623963	0,14190185	1,9010379	0,88075542	-0,04811614
6	1,74996	-1,8803375	-1,8647492	-0,92975509	0,39908624	0,14533	1,6848087	0,82456315	-0,17070429
7	2,2495	-1,8445768	-1,8487459	-0,59679049	0,2546649	0,13915473	1,6384701	-0,32637334	-0,13139677
8	2,64898	-1,8192401	-1,7474957	0,089906305	0,30932945	0,13957092	1,5865844	-0,22803432	-0,12118319
9	2,88808	-1,7965913	-1,8009541	0,34905559	0,24165301	0,13829747	1,1569586	-0,10071415	-0,1797888
10	3,11764	-1,7796891	-1,7358172	0,40260845	0,20808092	0,13395816	1,0943856	-0,1503956	-0,15445612
11	3,40938	-1,7544181	-1,8534469	0,39726961	0,21079053	0,12718414	0,75417137	-0,14476593	-0,19174594
12	3,697	-1,7382498	-1,8810842	0,38627684	0,15772793	0,12542617	0,85215962	-0,13470529	-0,16696268

1st Re
16th Re
1st Im
16th Im

Image 63: Example of exported Real and Imaginary data for 1st, 16th and 32nd harmonic

3D FFT cut export

The data that is cut from the 3D FFT can also be exported. To do this first go through the normal cut procedure as described in the **3D FFT cut** section.

Select the 2D graph widget and open the **Edit** menu, on the right upper section in Dewesoft X. Navigate to **Copy to clipboard** and **Widget data**.

The clipboard data is then easily pasted into other programs, for example, Excel.

	A	B
1	Frequency [H	acc/TimeFFT/X cut [-]
2	0	0,0153
3	3,052	0,0135
4	6,104	0,0034
5	9,155	0,0047
6	12,207	0,0065
7	15,259	0,0059
8	18,311	0,0028
9	21,362	0,0766
10	24,414	0,4195
11	27,466	0,6509
12	30,518	0,3579
13	33,569	0,0503
14	36,621	0,0006
15	39,673	0,0005
16	42,725	0,0005
17	45,776	0,0007
18	48,828	0,0011
19	51,88	0,0008
20	54,932	0,001
21	57,983	0,0009
22	61,035	0,0013
23	64,087	0,0024
24	67,139	0,002
25	70,19	0,0019

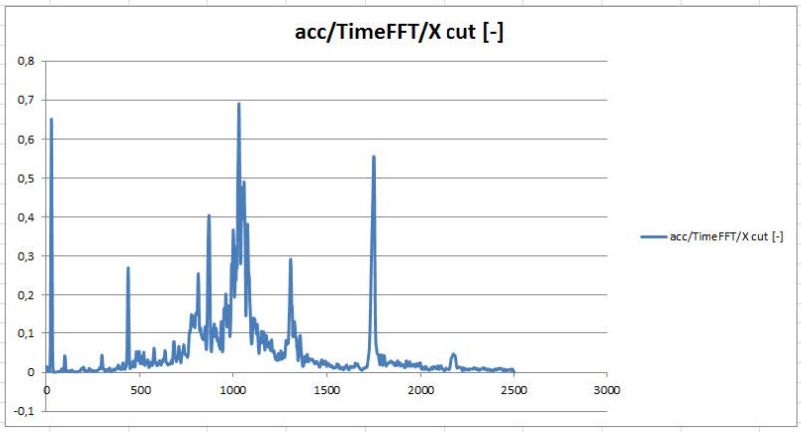


Image 64: Exported data to Excel

The copy data to clipboard function is also available on the standard FFT instrument.

Order Tracking Analysis Webinar

Order tracking method is a perfect tool to determine the operating condition of the rotating machines (resonances, stable operation points, determining a cause of vibrations). In this webinar, you will learn how to connect the sensors, configure the setup, perform the measurement and analyze the results.

[Video available in the online version]