DEWETRON

OXYGEN Order Analysis v1.4

TECHNICAL REFERENCE MANUAL

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Table of Content

1 PREFACE

OXYGEN's order analysis option can be used for analyzing noise and vibration of rotating machines providing the following features:

- Order analysis from 60 rpm to 100.000 rpm
- Up to 1000 speed steps
- Order resolution selectable from 0.01 to 1
- FFT-windowing and overlapping
- Amplitude output as RMS, Amplitude or Peak-Peak
- Adaptive AAF for order domain analysis
- Order extraction of selected orders
- Overall RMS channel

Benefits:

- Gapless analysis
- Order analysis with angle-based resampling and adaptive anti-aliasing filter
- Simultaneous analysis in order and frequency
- Simple configuration

1.1 INSTALLATION AND LICENSING

The order analysis option is automatically installed with every Oxygen R5.x (December 2019) and above. Once installed, the option needs to be licensed (if not done by DEWETRON factory already) and activated.

The license can be updated under the System Information tab (see Figure 1-1:).
This requires a *.lic-file provided by DEWETRON. A license update requires a restart of Oxygen.

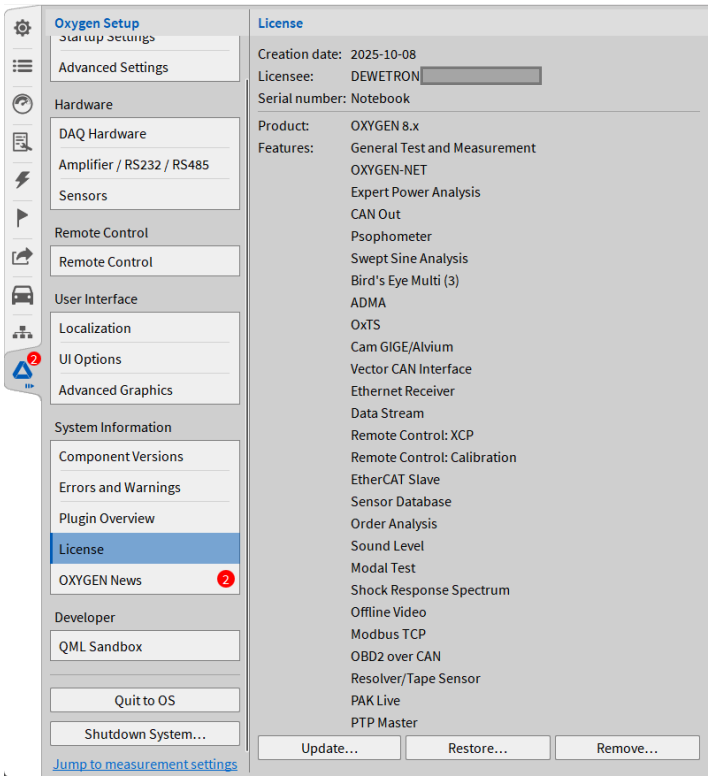

Figure 1-1: Updating the OXYGEN-license

1.2 REQUIRED HARDWARE CHANNELS

The OXYGEN order analysis option requires three different input signals: a speed channel [rpm], an angle channel [°], and an input signal for analysis. The speed and angle information can be acquired from the test object using a tachometer sensor or an encoder, for example. Common input signals for order analysis are vibration or sound signals measured with accelerometers and microphones.

To acquire the signal from a speed sensor (tacho or encoder), a counter (CNT) hardware channel is required. The following TRION-boards provide one or more counter channels:

- TRION-CNT: 6 channels for encoders (A,B,Z output) or tacho sensors (single output)
- TRION-BASE: 2 channels for encoders (A,B,Z output) or tacho sensors (single output)
- TRION-TIMING or TRION-VGPS: 1 channel for encoders (A,B,Z output) or tacho sensors (single output)
- TRION-1802/1600-dLV: 2 channels for encoders (A,B,Z output) or tacho sensors (single output)
- TRION(3)-18x0-MULTI: 2 channels for tacho sensors (single output)
- TRION-2402-dACC: 2 channels for tacho sensors (single output)
- TRION-1620-ACC: 1 channel1 for tacho sensors (single output)
- Chassis controller: 4 channels whereas 2 can be used for encoders (A,B,Z output) and 2 support tacho sensors (single output)

OXYGEN automatically calculates both rotation speed and angle from a speed sensor signal based on the sensor input and the OXYGEN counter software settings.

If the order analysis uses an IEPE acceleration signal or airborne sound from a microphone, an IEPE-enabled hardware channel is required. The following TRION modules support IEPE mode:

- TRION(3)18x0-MULTI
- TRION-2402-dACC
- TRION-1620-ACC
- TRION-2402-MULTI
- TRION-2402-dSTG

If the signal for which the order analysis shall be determined is coming from a strain gage sensor, a bridge input provided by one of the following TRION-boards is required:

- TRION(3)18x0-MULTI
- TRION-2402-MULTI
- TRION-2402-dSTG

For further hardware specifications, please refer to the latest version of the technical reference manual of the TRION series modules available on the CCC-portal (https://ccc.dewetron.com/).

2 SOFTWARE CONFIGURATION

This manual only refers to the OXYGEN Order Analysis option. For general software operation instructions, please refer to the latest version of the OXYGEN technical reference manual available on the CCC-portal (https://ccc.dewetron.com/).

2.1 CONFIGURE INPUT CHANNELS

1. Connect sensors for acceleration and angle of rotation
2. Select settings for the acceleration sensors in the channel setup (mostly IEPE mode and measuring range)

3. Setup counter input for the speed / angle measurement in the channel setup

Remark: The unit of the rotation angle must be specified in degree [°] and the unit of the running speed must be specified in revolutions per minute [rpm].

Encoder settings

When using an encoder with A, B, Z signals (see Figure 2-1:):

- Open detail setup of Main Counter Channel, set Counter Mode to *Encoder* and enter the number of pulses per revolution

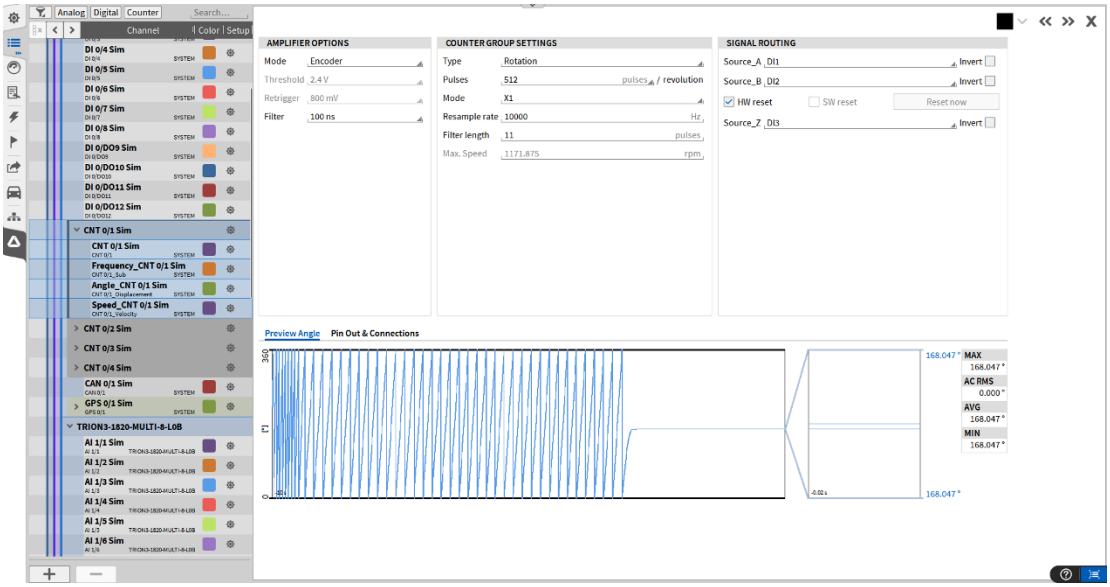

Figure 2-1: Counter channel settings or Encoder

Tacho settings

When using a tacho sensor with a single output (see Figure 2-2:):

- Open detail setup of Main Counter Channel, set counter mode to *Events*, enter the number of pulses per revolution and, if necessary, change the *Source* channel. Additionally, check *HW-Reset* (if available) otherwise use *SW-Reset*.

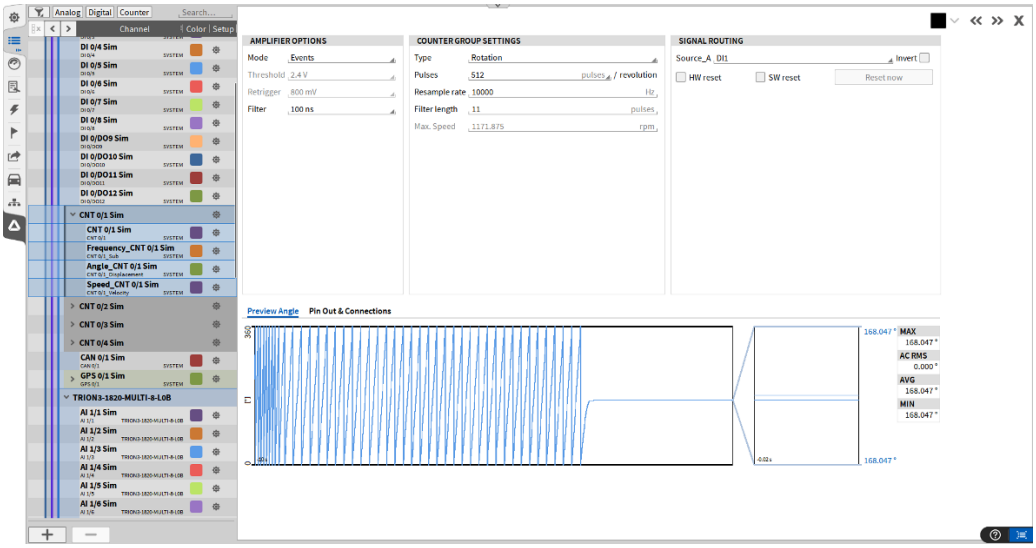

Figure 2-2: Counter channel settings for tacho sensors

2.1.1 SAMPLE RATE

Sample rate must be the same for all channels involved in the order analysis. It´s best to select the counter channels involved (CNT, Frequency, Speed and Angle) plus the analog channels to be analyzed, and to change their sample rate all together.

The recommendation for a minimum sample rate is:

$$Minimum\ sample\ rate = \frac{Maximum\ speed\ [rpm]}{60} * Highest\ order * 3$$

Example: 6000 rpm / 60 * 100 * 3 => **30 kHz**

To change the sample rate, go to the data channels and click on the sample rate (see Figure 2-3:)

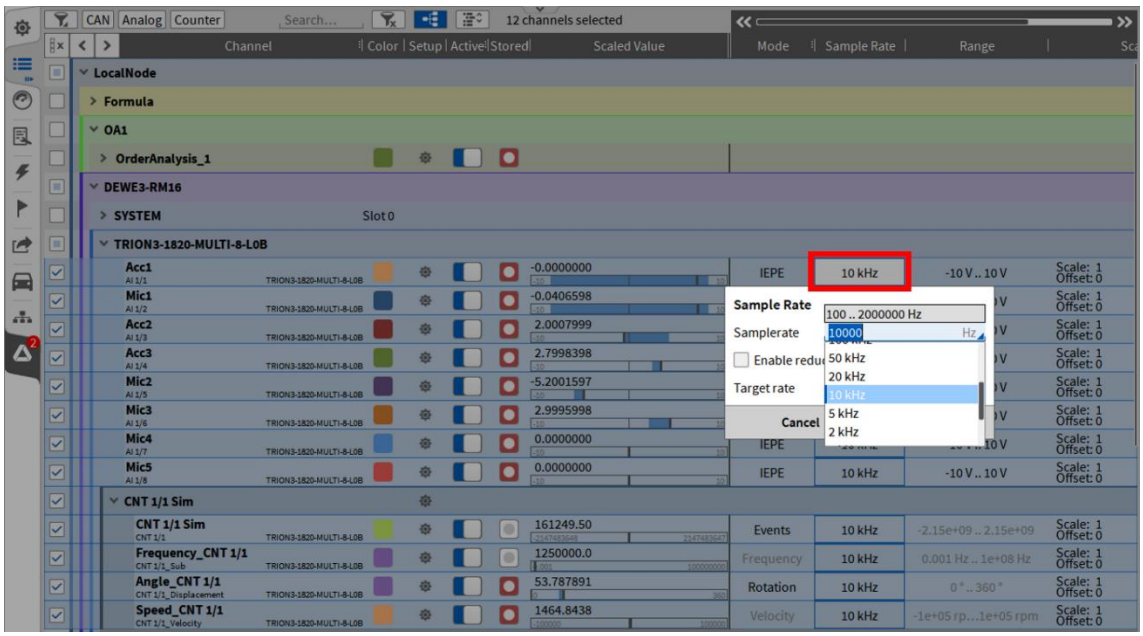

Figure 2-3: Setting up the sample rate

2.2 CREATE AN ORDER ANALYSIS CHANNEL

Either create order analysis module without prior selection channels: Press (+), select the *Order Analysis* module in the Optional Calculations tab. (see Figure 2-4:):

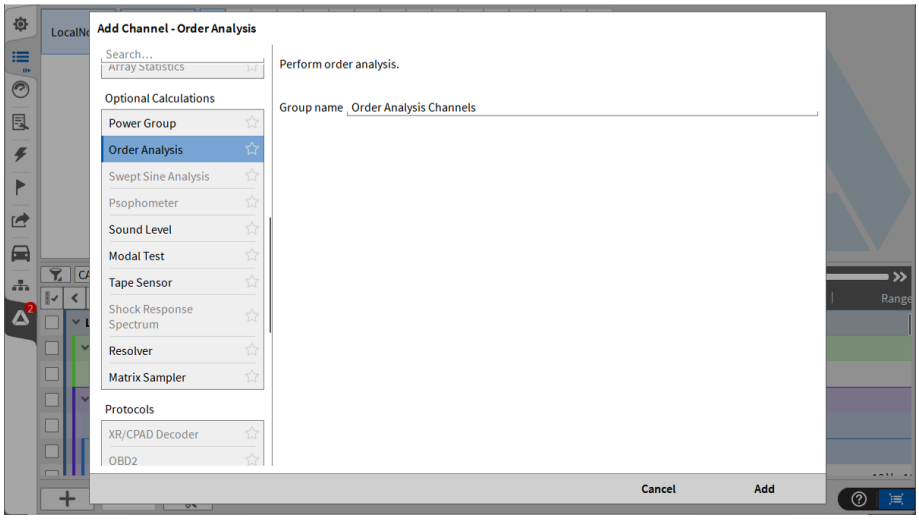

Figure 2-4:Creation of Order Analysis module; Option 1

Or create an order analysis module with selection of Speed, Angle and Signal channels:(see Figure 2-5:): Select speed channel -> angle channel -> signal 1…signal n and then press (+) and select the *Order Analysis* module:

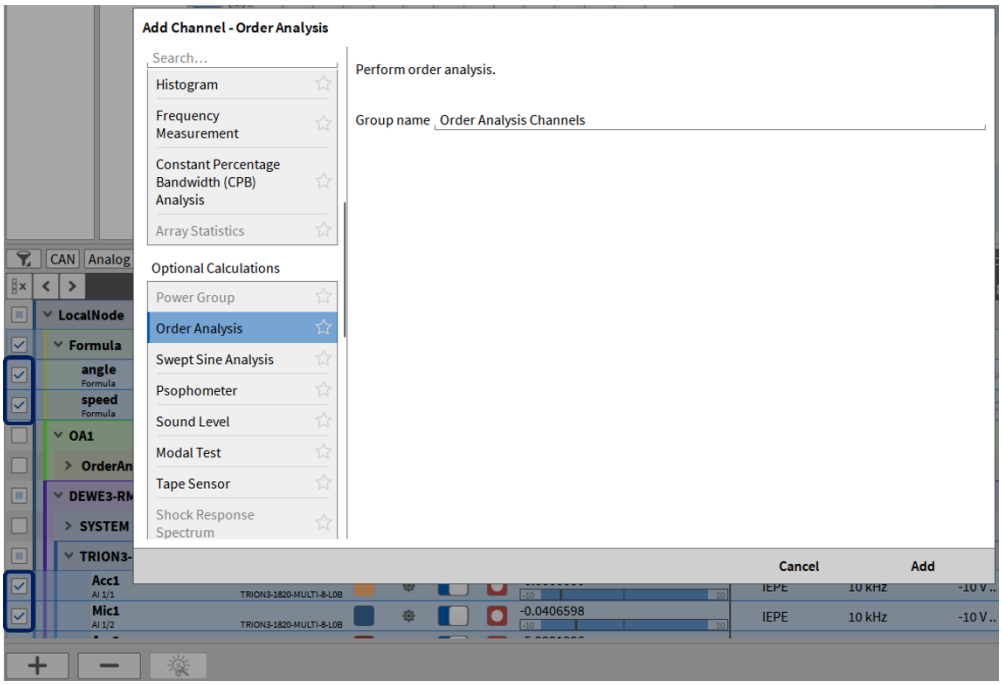

Figure 2-5:Creation of Order Analysis module; Option 2

After creating an Order Analysis the default settings can be adjusted to the measurement application: (see Figure 2-6)

① Define *Group name* for one or more order analysis
② Select *Minimum speed* from 60 up to (maximum speed -1)
③ Set *Maximum speed* from (minimum speed +1) up to 100.000
Possible range from minimum to maximum speed: 2 decades (i.e. from 100 to 10000 rpm)
④ Set *Speed resolution* for the matrix display
⑤ Select speed direction:
   i. *Both*: Update will be performed if speed goes up or down
   ii. *Down*: Update will be performed only if speed goes down
   iii. *Up*: Update will be performed only if speed goes up
⑥ Set Order resolution from 0.01 to 1
⑦ Set the amplitude type of the order analysis as RMS, Amplitude or Peak-Peak (Up to OXYGEN 7.7 the output of the order analysis was always RMS)
⑧ Enter the order to be extracted from the Order Spectrum
⑨ Activate Overall RMS value – Calculates the RMS for each input channel over its full order spectrum. The RMS value will be updated for each new input sample:

$$Overall_{RMS}\sqrt{\sum_{i=1}^{n} Order_i^2}$$

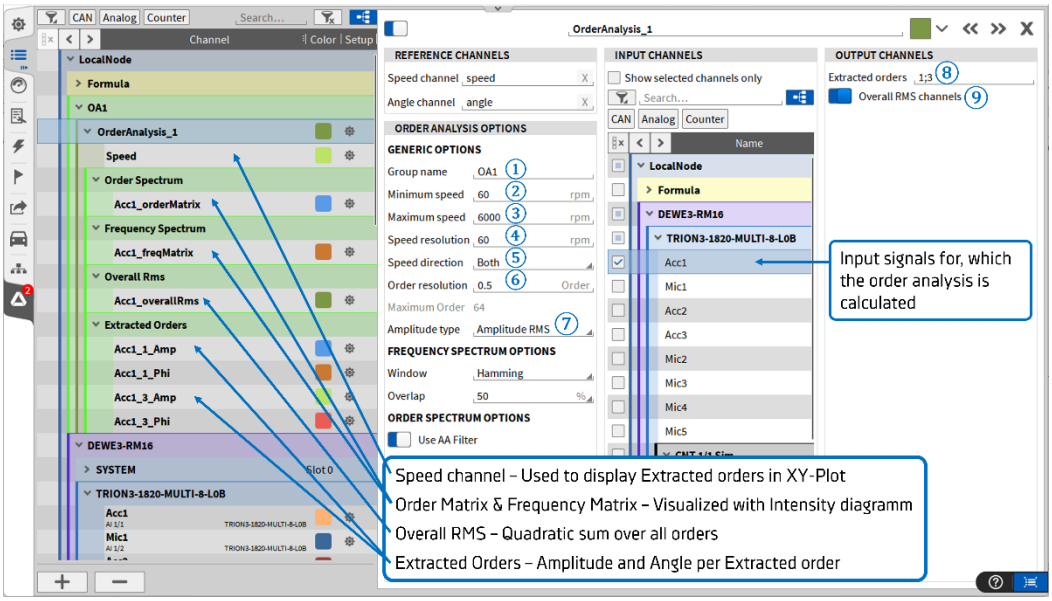

Figure 2-6: Order Analysis settings

Remark: It is possible to select several signals for which the order analysis should be performed.

2.3 CREATING A SETUP ON THE MEASUREMENT SCREEN

- Drag order matrix channel (= orders over speed) onto the screen (see Figure 2-7:)

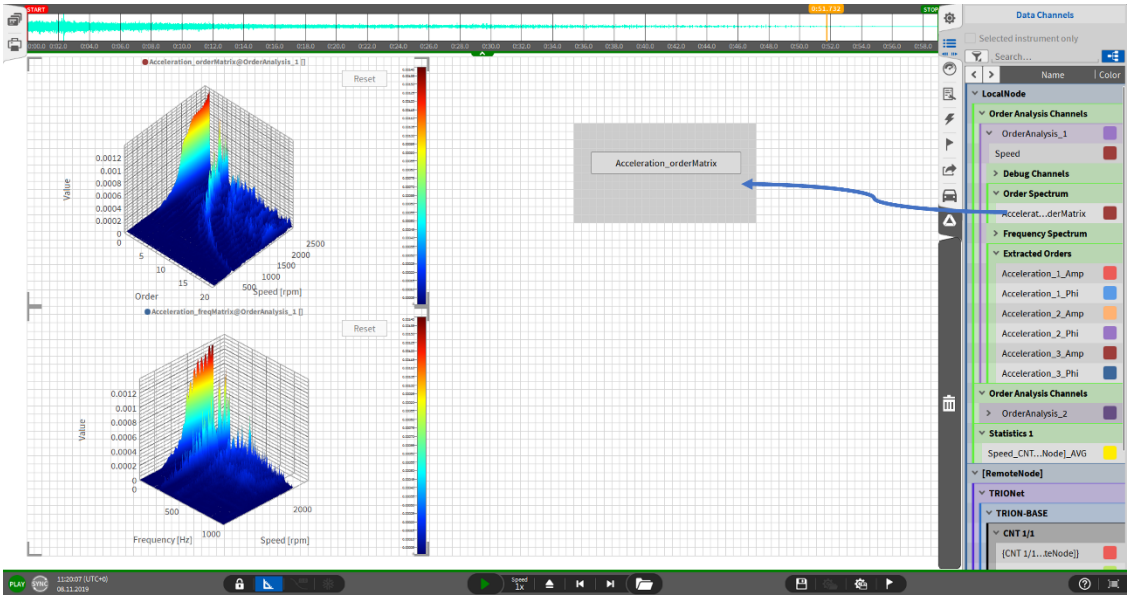

Figure 2-7:Display order matrix on the measurement screen

- Drag the frequency matrix channel (= FFT over speed) onto the screen and adjust the instruments (see Figure 2-8:)

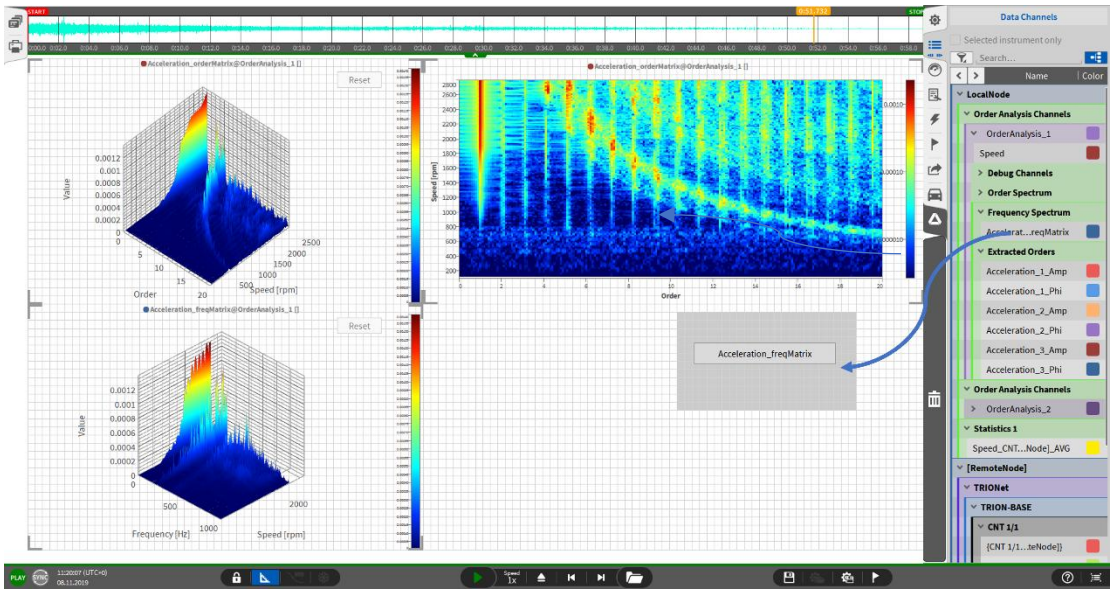

Figure 2-8:Display frequency matrix on the measurement screen

- If necessary, enable the logarithmic scale (for the color palette) per instrument (see Figure 2-9:)
- For enabling the logarithmic scale, the instrument properties must be accessed which is possible by double clicking on the respective instrument.

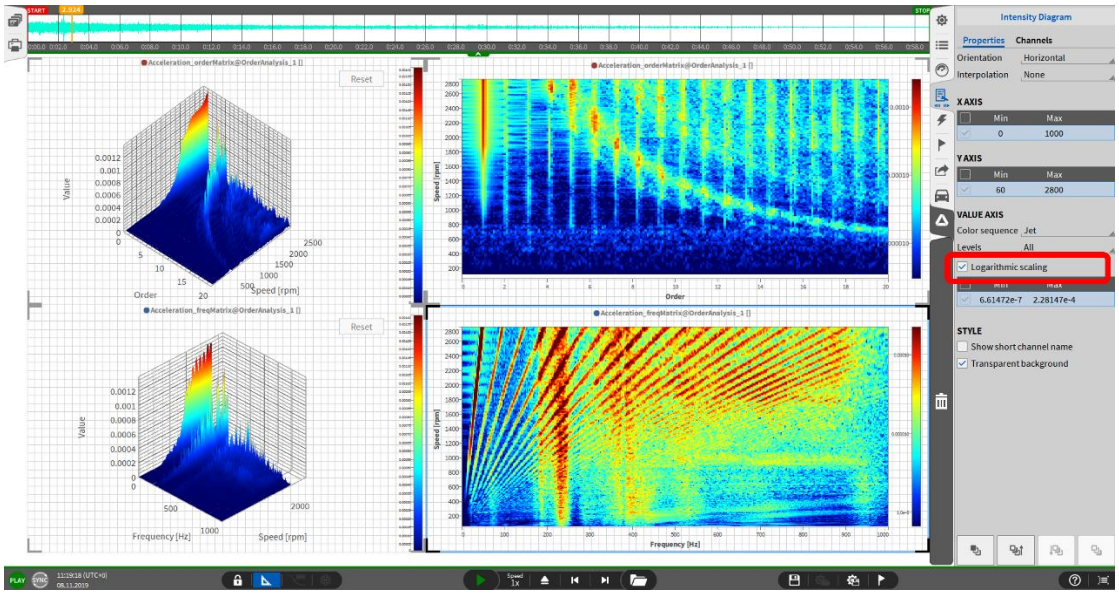

Figure 2-9:Logarithmic scaling of the intensity matrix

- Optional, add instrument for the current speed (e.g., Speed_CNT 4/1)
- Optional, create recorder to display the values of the extracted order

3 DATA RECORDING

- Push Record Button (see red arrow in Figure 3-1:)
- Runup the machine
  The displays should now fill with data
  If needed, adjust the "Contrast" with the color control, adjust the range with CTRL + mouse wheel on the color bar (see Figure 3-1:)

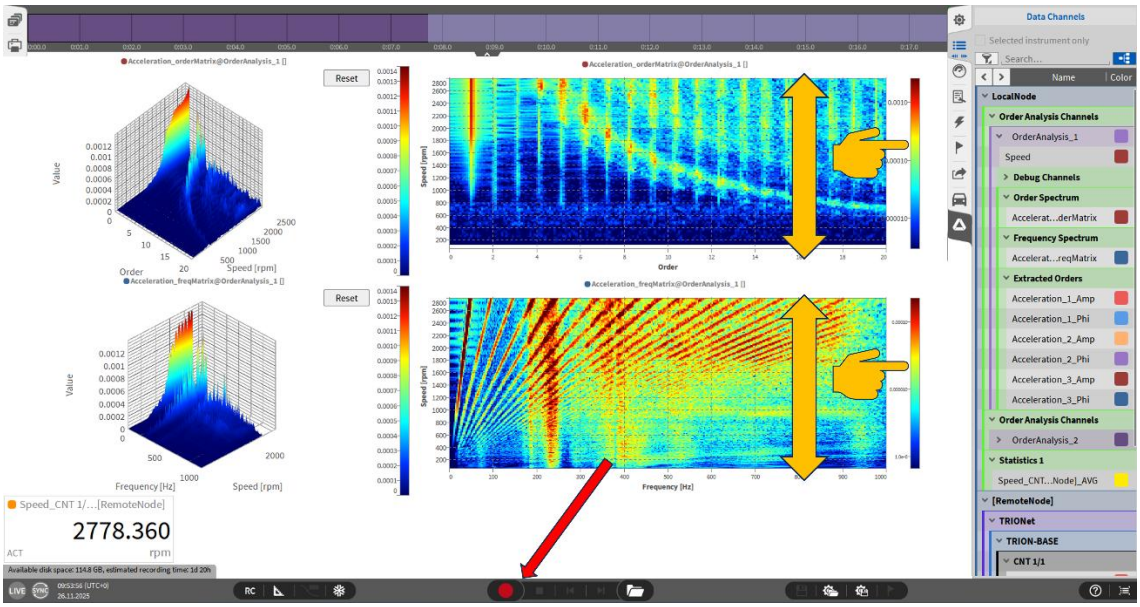

Figure 3-1:Changing the contrast of the intensity charts

- Observe the measurement
- Stop the measurement
- Open Data file
- View the data
- Zoom of the instruments (see arrow button marked red in Figure 3-2:)

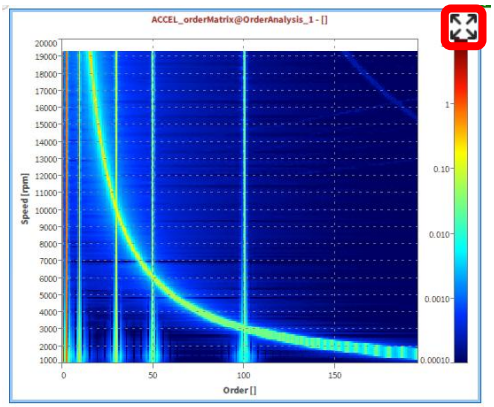

Figure 3-2:Enlarge instruments to the full screen

- Zoom in the Instrument
  - With mouse wheel
  - With box zoom: Right click and move the mouse
  - Undo with right mouse button

4 OUPUT SIGNALS

The order analysis module outputs the following channels for every input channel:

- Speed: Rotation speed of the DUT; Update time depends on the min/max speed and the speed resolution as well as the instant of time the DUT passes the certain speed interval
- Order Spectrum: An order spectrum including the Order on the X-Axis, the engine speed on the Y-Axis and the amplitude color-coded on the Z-Axis is determined for every input signal;
- For data export, this channel has a matrix structure; The orders are in the columns increasing from left to right and the running speed is in the lines increasing from top to bottom
- Frequency Spectrum: A frequency spectrum including the frequency on the X-Axis, the engine speed on the Y-Axis and the amplitude color-coded on the Z-Axis is determined for every input signal.
- For data export, this channel has a matrix structure; The frequency is in the columns increasing from left to right and the running speed is located in the lines increasing from top to bottom.
- Extracted Orders: For every order that is extracted, a time-domain amplitude channel and phase channel is calculated. The channels are updated every time the corresponding *Speed* channel is updated.

4.1 ORDER ANALYSIS TEMPLATE

To speed up the interpretation of an order analysis, there is a default template in the measurement screen at the same location where saved measurement screen templates are saved (see Figure 4-1).

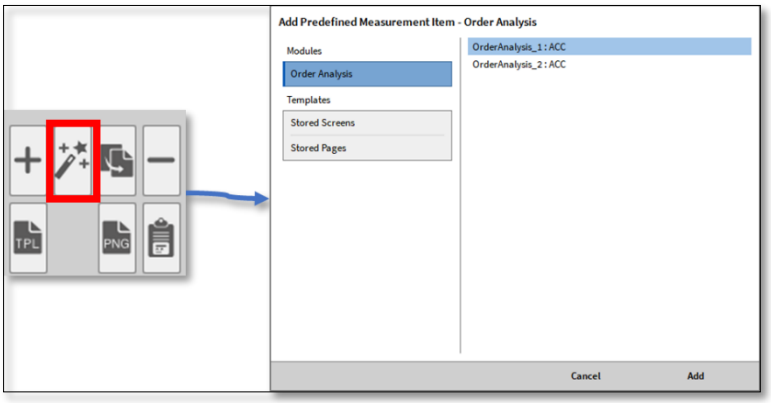

Figure 4-1: Enlarge instruments to the full screen.

The resulting template is displayed in Figure 4-2.

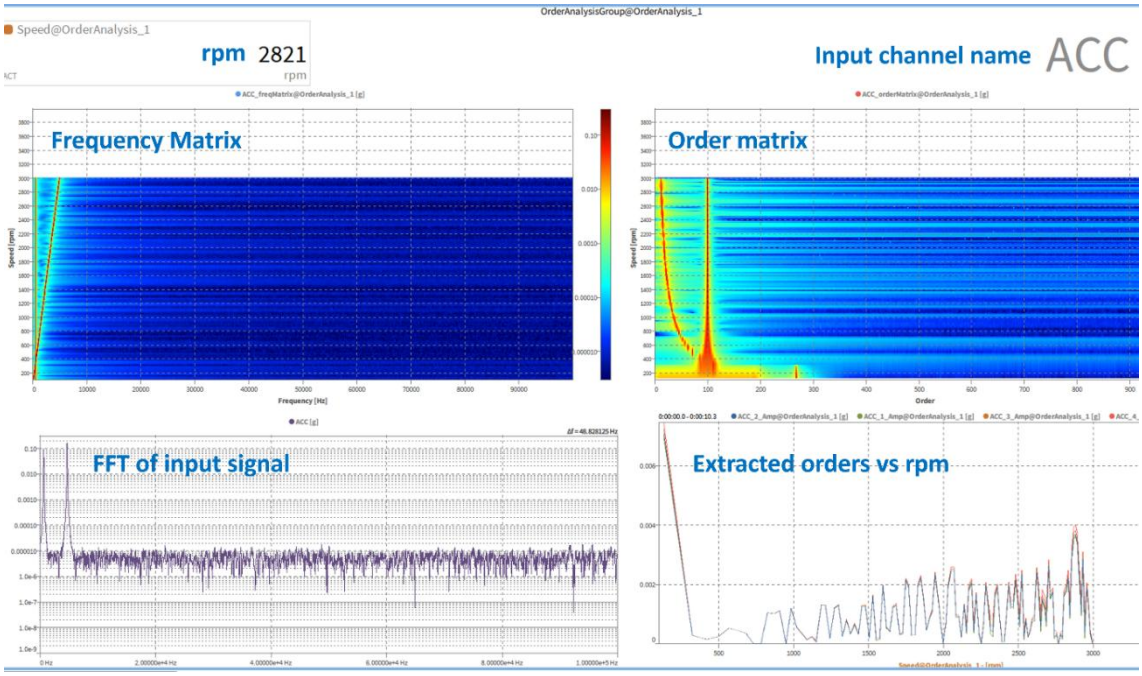

Figure 4-2: Template order analysis screen.

5 OFFLINE-SUPPORT

If a data file including the speed and angle signal of a rotating machine and the signal for which an order analysis shall be determined already exists, the order analysis can also be determined during the post processing in the following manner.

- Open the data file
- Go to the channel setup and create an order analysis module
- Adjust settings and add extracted orders if necessary (see Figure 2-6)
- Exit menu, calculation starts automatically
- Place additional instruments like a Recorder or an X/Y-Plot (see Figure 5-1)

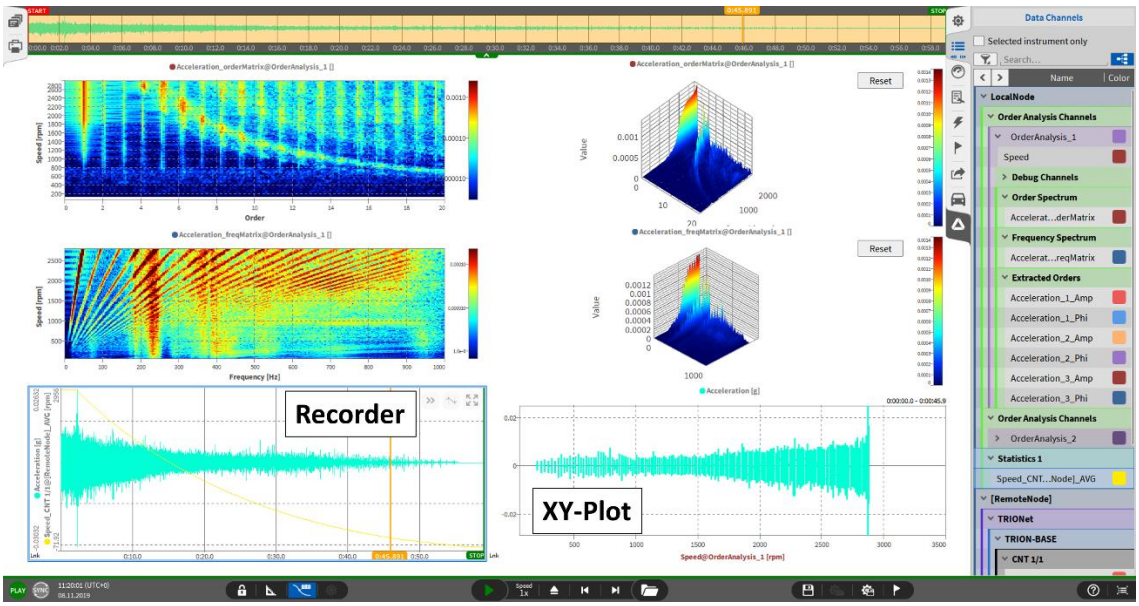

Figure 5-1: Offline order analysis

6 EXPORT DATA

There are several possibilities to export the order analysis data which are explained below.

6.1 EXPORT DATA INTO DIFFERENT FORMATS

To export the data, go to the export menu by selecting the certain menu tab on the menu bar (see yellow box in Figure 6-1).

- OXYGEN supports data export into different formats like*.txt, *.csv, *.xlsx, *.mat and *.mdf4.0/4.1 for example.
- To export the data, select the channels to be exported with a check mark right to their name (see red box in Figure 6-1)
- Go to the options section, select the individual export format and the corresponding options below. Click the export button to start the data export (see blue box in Figure 6-1)
- It is also possible to automatically export the data in one of the stated formats automatically after measurement end (see green box in Figure 6-1)

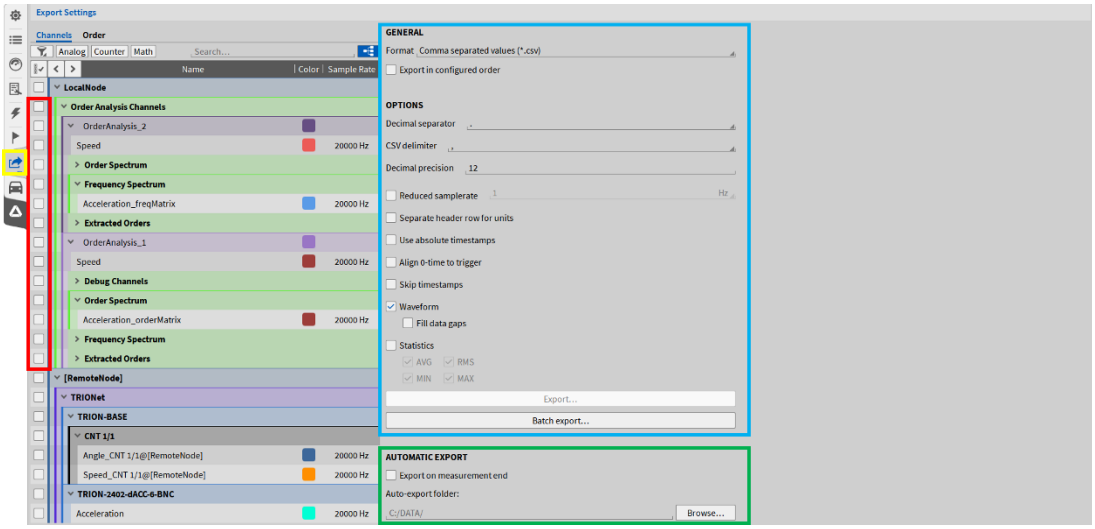

Figure 6-1: Export menu - Overview

6.2 COPY – PASTE DATA INTO DIFFERENT SW PACKAGES

It is possible to copy and paste the order spectrum and frequency spectrum data displayed in an intensity diagram into another software package, like Excel (see Figure 6-2).

- Select the intensity diagram of the data you want to copy and press CTRL+C
- Open the software package, like Excel, to which the data shall be pasted and press CTRL+V
- As the data is stored to the clipboard, it can also be pasted into other software packages but Excel.

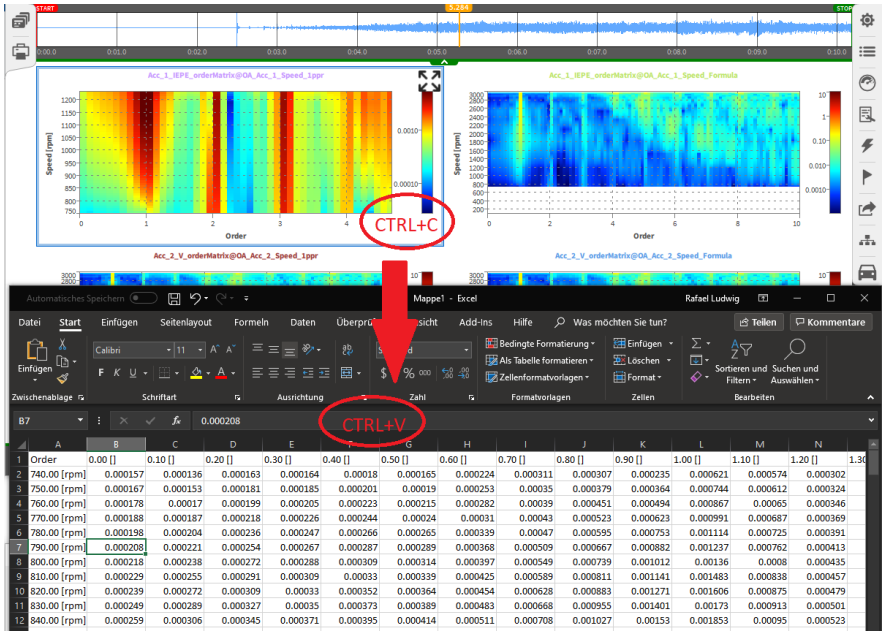

Figure 6-2: Copy and paste data from OXYGEN into Excel

6.3 SAVE DATA AS IMAGE FILE

It is possible to save the order analysis data as an image file. (see Figure 6-3)

- Select the certain instrument that shall be saved. Open the small view of the Screen menu and press the *png*-button to export the data into a *.jpeg or *.png-file or press the *copy*-button to copy the data as image to clipboard and paste the image into another software.

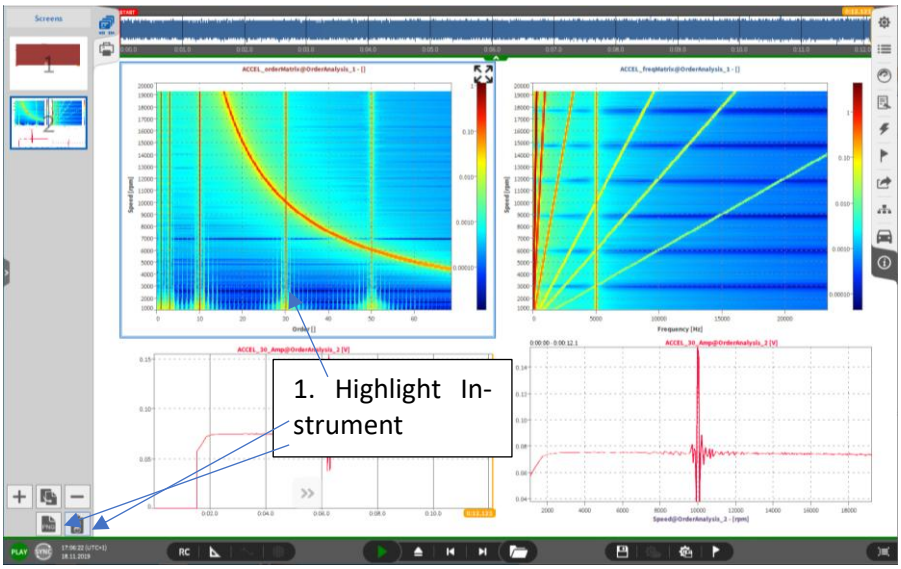

Figure 6-3: Save data as image file

7 TECHNICAL CALCULATION REMARKS

The following section includes important hints for the calculation methods referring to the output channels of the order analysis module.

7.1 SAMPLE RATE

- Recommendation for minimum sample rate:
- $SR_{min}[Hz] = 3 * \frac{Max_{speed}[rpm]}{60} * highest\ order$

Example: Maximum Speed = 6000 rpm / 60 * 100 * 3 = 30 kS/s
Highest Order: 100

- $SR_{min}[Hz] = 3 * \frac{6000}{60} * 100 = 30\ kHz$

7.2 SPEED RANGE

- Minimum speed: 60 rpm
- Maximum speed: 100 000 rpm
- Possible range from minimum to maximum speed: 2 decades (i.e. from 100 to 10000 rpm)
- Speed resolution: up to 1000 speed steps
- The speed resolution is limited to 1000 steps (and therefore both the order and the frequency matrix are limited to 1000 lines).
- This was done to avoid RAM overload and to ensure proper data handling for post processing in 3rd party SW packages.
- Speed intervals: Calculation and sorting of speed values in different intervals
- Depending on the settings for *Minimum speed*, *Maximum speed* and *Speed resolution*, the speed is split into the following intervals (This applies for the speed resolution of the order and the frequency spectrum):

Interval	Label / Interval name	Lower boundary (included)	Upper boundary (excluded)
Interval 1	ceil(min_speed / speed_resolution) * speed_resolution	min_speed	Label + speed_resolution/2
Interval 2	Interval 1 + speed_resolution	Label - speed_resolution/2	Label + speed_resolution/2
Interval 3	Interval 2 + speed_resolution	Label - speed_resolution/2	Label + speed_resolution/2
…	…	…	…
Interval k	floor(max_speed / speed_resolution) * speed_resolution	Label - speed_resolution/2	max_speed

- Example1: min_speed = 60, max_speed = 6000, speed_resolution = 100

Interval	Label / Interval name	Lower boundary (included)	Upper boundary (excluded)

Interval 1	100	60	150
Interval 2	200	150	250
Interval 3	300	250	350
…	…	…	…
Interval k	5900	5850	6000

- If a certain speed interval is not passed during the run up or the coast down of the engine was too fast, the data between the measured upper and lower interval will be linear interpolated to fill the interval gaps with data.

- Example:

Interval	Label / Interval name	Data determined	Data displayed
Interval 1	100	Yes	Determined
Interval 2	200	Yes	Determined
Interval 3	300	No	Interpolated between 200 and 400 rpm
Interval 4	400	Yes	Determined
Interval 5	500	No	Interpolated between 400 and 600 rpm
Interval 6	600	Yes	Determined
Interval 7	700	No	Interpolated between 600 and 900 rpm
Interval 8	800	No	Interpolated between 600 and 900 rpm
Interval 9	900	Yes	Determined

7.3 FREQUENCY AND ORDER MATRICES

Both the frequency matrix and the order matrix are calculated in 2 parallel stages. The frequency matrix is calculated using a standard FFT algorithm to transform the time signal in fixed intervals (2^n) into the frequency domain and the order matrix is calculated based on a FFT transforming the time signal per every revolution into the frequency domain. More details can be found in the following sections.

The frequency and order matrices contain no time dependent data. This means that the matrices are filled continuously with data while the measurement is running but the data will be stored without timestamping. When the data is analyzed in *PLAY* mode the content of the matrix will not change but remain in the same manner as at the end of the measurement.

If the same speed step is passed several times during the measurement, only the maximum value will be stored to each matrix column. Minor values will be overwritten and not stored to the data file.

7.3.1 Determination of the Frequency Matrix

- The FFT size depends on the minimum and maximum speed and the order resolution.
- The maximum FFT size in samples is limited to 4096. This leads to a maximum number of 2048 FFT bins in the frequency matrix.
- The limited number of 2048 FFT bins (and therefore 2048 matrix columns from 0 Hz to $\frac{f_S}{2}$ Hz) was done to avoid RAM overload and to ensure proper data handling for post processing in 3rd party SW packages.
- The user can select between the following window functions for the FFT determination:
- Hamming (default), Hanning, Rectangular, Blackman, Blackman-Harris, Flat-top, Bartlett (Tri-angular)
- Choose an overlapping factor in time domain of 0%, 50%, 75%, 80% and 90%

7.3.2 Determination of the Order Matrix

General:

- The order resolution can be set from 0.01 to 1.
- The maximum order depends on the order resolution. The maximum number of columns for the order matrix is 2048 to avoid RAM overload and to ensure proper data handling for post processing in 3rd party SW packages.
- The maximum order is displayed at the bottom of the *Generic options* of the *order analysis setup*.
- If the order resolution is not specified as an inverse integer multiple of 1, the order resolution will be rounded automatically to the next lower inverse integer multiple of 1.
- I.e. 0.4 will be rounded to 1/3
  0.6 will be rounded to 0.5

The calculation steps from the raw input signal in time domain to the order matrix are the following:

- Separation of the raw input signal into signal blocks per revolution (see Figure 7-1: top); One block represents one revolution; to achieve a high accuracy, the rotation angle is required therefore.

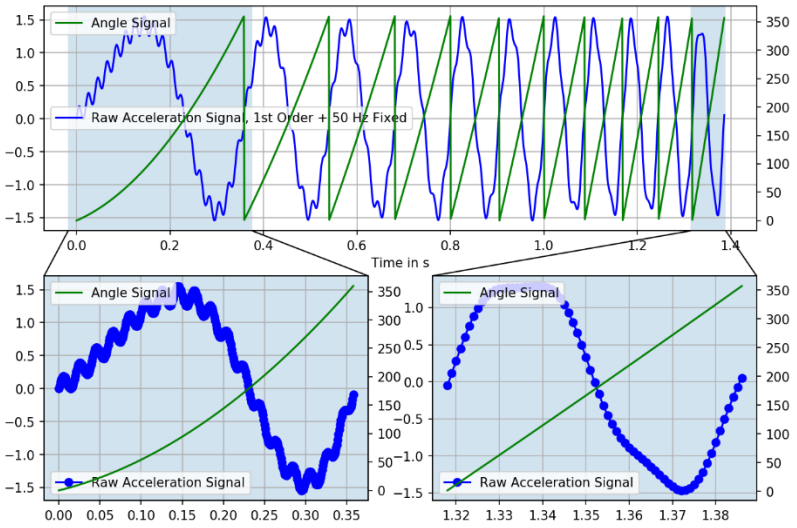

Figure 7-1:Separation into separate blocks per revolution (top); Decreasing number of samples with increasing running speed (bottom)

As the running speed of the DUT will change continuously and the sample rate is constant , the number of samples per revolution will decrease with increasing running speed (see Figure 7-1: bottom).

- The average speed per revolution is determined and stored to the *Speed* channel which is output by the order analysis module

- To avoid aliasing during the FFT explained in the following below, the raw signal will be filtered with an adaptive anti-aliasing filter (lowpass filter) (see section Figure 7-2).

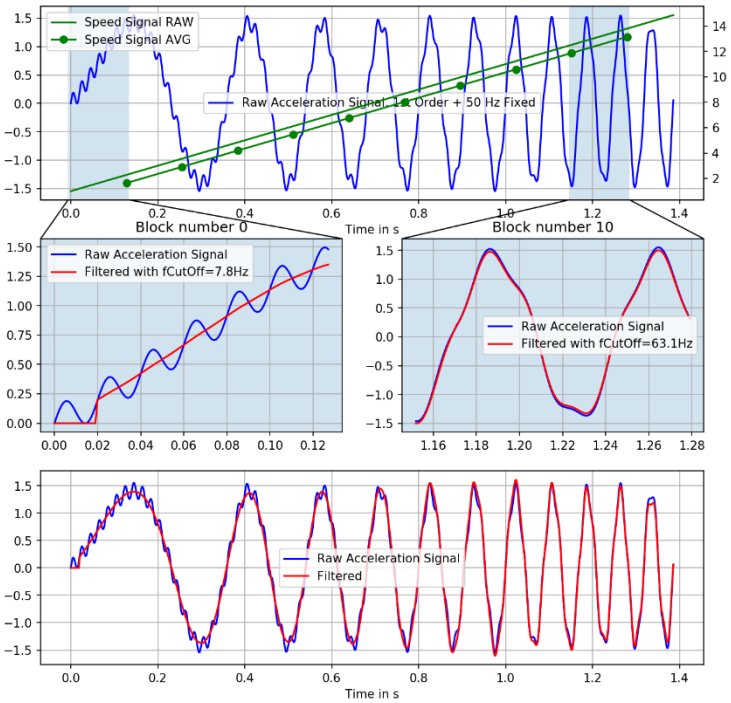

Figure 7-2: Impact of the anti-aliasing filter to the raw signal

- Due to the fact mentioned above that the numbers of samples per revolution is decreasing with increasing running speed, the signal will be resampled to a defined number of samples per revolution (see Figure 7-3).

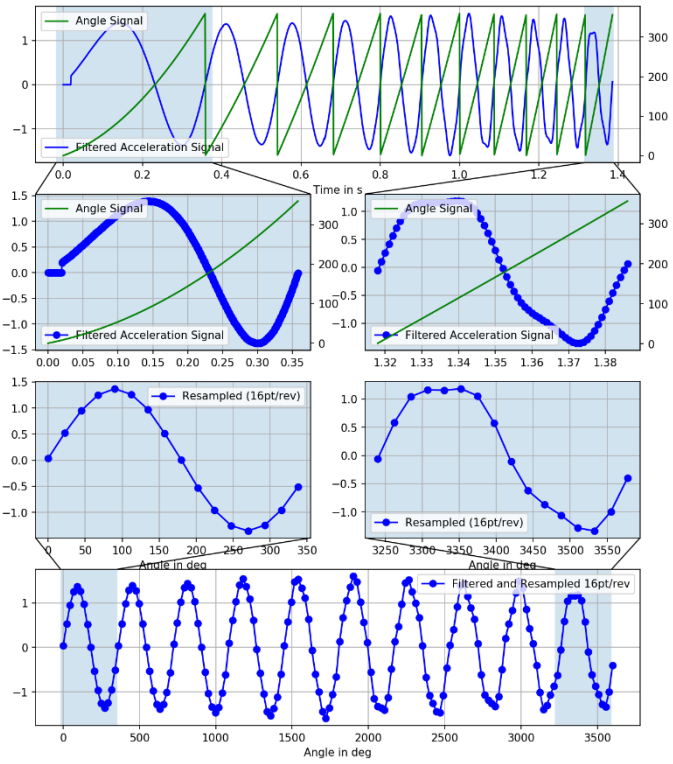

Figure 7-3: Resampling to a defined number of samples per revolution

An accurate angle signal is required for this step. The more angle steps per revolution delivered by the speed sensor, the more accurate the resampling algorithm will work. This means that an encoder delivering 1800 pulses per revolution will lead to more accurate results than an encoder delivering 512 pulses per revolution as the angle resolution is better.

A linear interpolation algorithm is used for resampling.

The number of samples per revolution depends on the sample rate and the maximum speed.

- The order spectrum is now calculated by transforming the resampled signal (fixed number of samples per revolution) into the frequency domain.
- The difference to the output spectrum to the usual frequency spectrum is hereby that the frequency is no longer plotted along the x-axis but the order itself (see Figure 7-4). Thus, the order spectrum can be directly extracted from this spectrum.

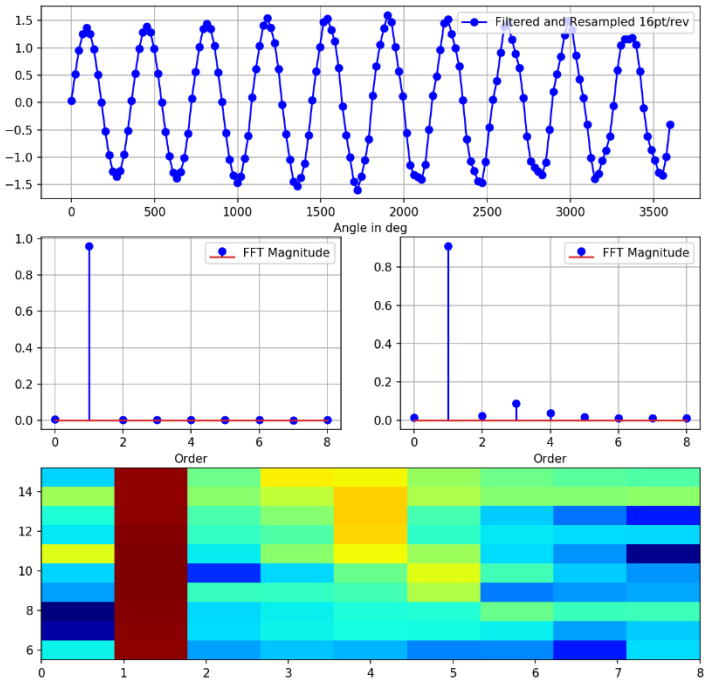

Figure 7-4: Determination of the order spectrum

Remarks:

- The *Overlapping* factor specified in the *Frequency spectrum options* of the order analysis settings is also applied to the order spectrum.
- The *Window* function specified in the *Frequency spectrum options* of the order analysis settings is **not** applied to the order spectrum but **only** to the frequency spectrum.

7.3.3 EXTRACTION OF ORDERS FROM INTENSITY DIAGRAM

It is possible to extract the order from an intensity diagram via the cursor position (see Figure 7-5). To enable the order extraction, press the icon on the upper right corner of the intensity diagram (①) and move the cursor in the diagram to the desired order. The size of the order extraction can be expanded by dragging the grey bar between the two diagrams. For better visualization, enable logarithmic scaling.

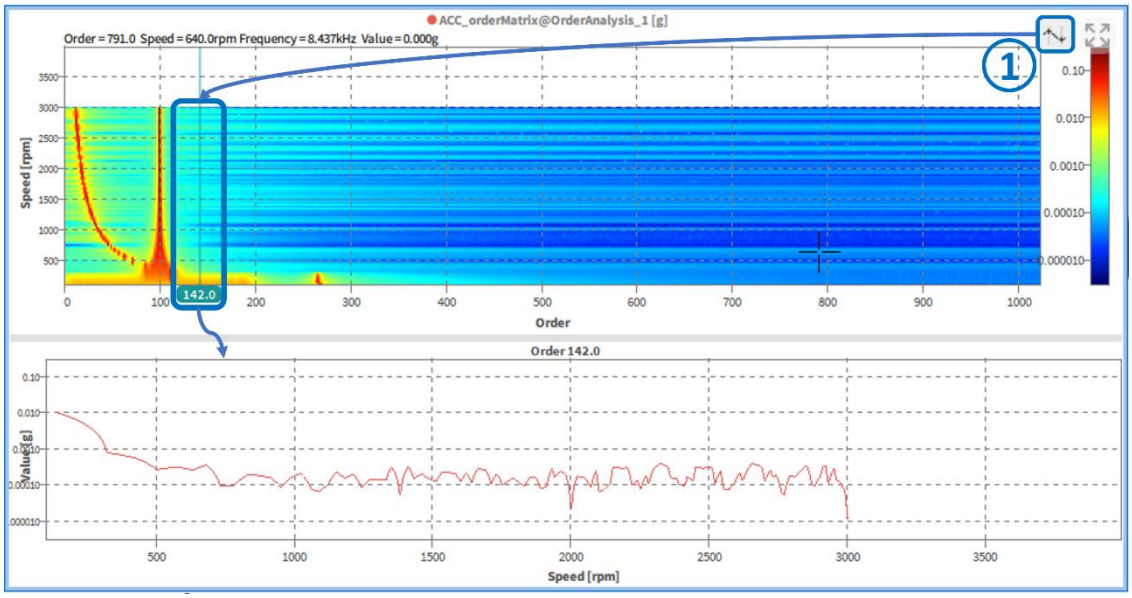

Figure 7-5: Extraction of order from intensity diagram.

8 LIST OF FIGURES