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Rotational and Torsional Vibration

Users Manual

Version: 1.0

Thank you!

Thank you very much for your investment in our unique data acquisition systems. These are top-quality instruments which are designed to provide you years of reliable service. This guide has been prepared to help you get the most from your investment, starting from the day you take it out of the box, and extending for years into the future.

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1.1 Safety instructions

Your safety is our primary concern! Please be safe!

Safety symbols in the manual

WARNING	Calls attention to a procedure, practice, or condition that could cause body injury or death.

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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 GmbH assumes no liability for the customer's failure to comply with these requirements.

1.2 About this document

This is the Users Manual for Rotational and Torsional Vibration Version 1.0.

1.3 Legend

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

IMPORTANT 	Gives you an important information about a subject. Please read carefully!

HINT 	Gives you a hint or provides additional information about a subject.

EXAMPLE 	Gives you an example to a specific subject.

2 Introduction

The “Torsional Vibration” software option of DEWESoft™ is used to obtain - or enhance an existing Dewesoft system to - a rotational/torsional vibration monitoring and analyzing solution, for research, development and optimization. With the small form factor of the Dewesoft instruments (e.g. SIRIUS, DEWE-43, …) the perfect mobile solution for test engineers and consultants is born.
Torsional and Rotational vibration are calculated, as well as the corresponding velocities, the software can compensate uncentered mounting of the sensor and can also take care about the gearbox ratio. Furthermore the possibilities of DEWESoft™ allow angle-domain visualisation and export.

With DEWESoft™ also data from other sources: e.g. Video, CAN, Ethernet, … are perfectly synchronized in one datafile.

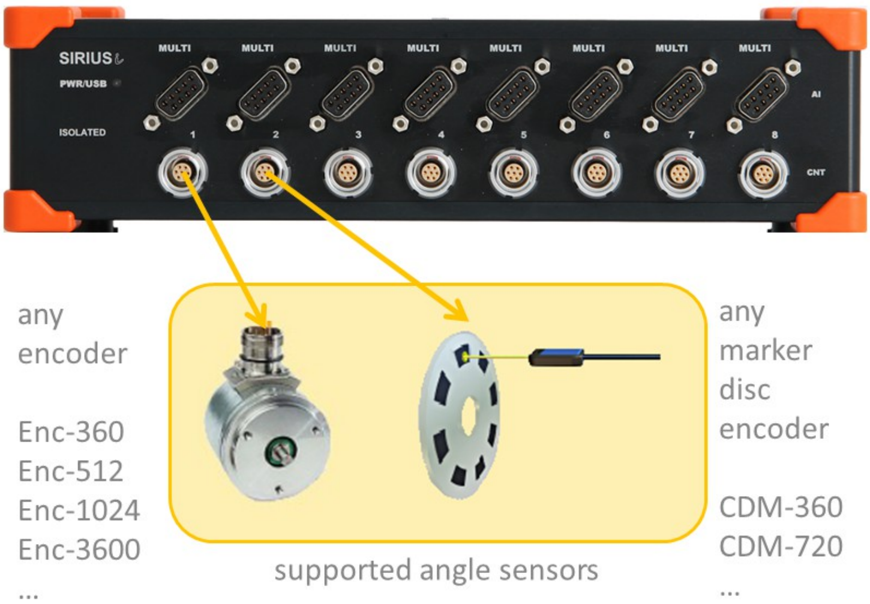
If the powerful integrated post processing features of DEWESoft™ are not enough, you can even export the data to several different file formats.

In addition to Torsional Vibration, the system can be expanded with the Ordertracking option to complete the picture of the measurement situation.

2.1 System Overview

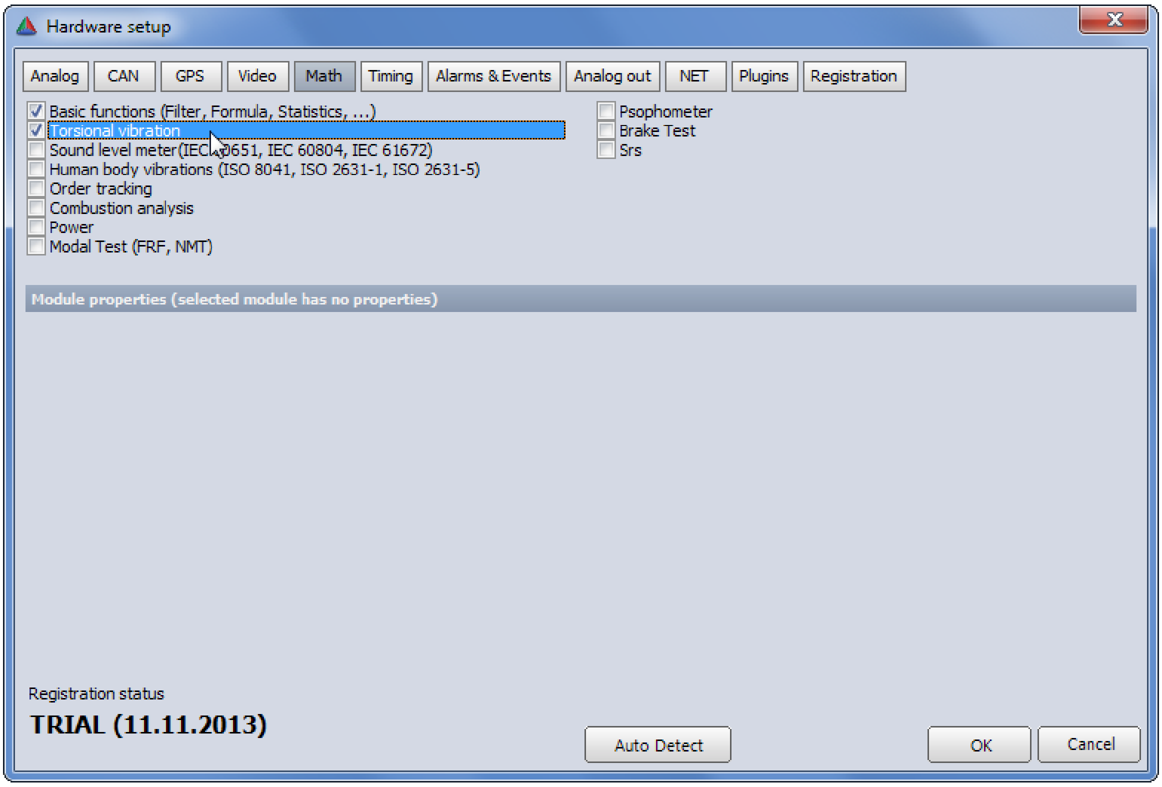
As the torsional vibration measurements are very critical in terms of accuracy, only precise counter sensors are supported. At least one (Rotational vibration), but usually two (Torsional vibration) encoders are necessary.

Either an encoder or a special RIE sensor can be used. The RIE sensor has less resolution, but is much less sensitive to vibrations (which could damage standard encoders over time).



2.2 Enabling TV (includes RV) module

Like many additional mathematics modules also Torsional Vibration is an option to the standard DEWESoft™ package and needs to be enabled in the Hardware setup: Enter <Settings> <Hardware Setup> and then <Math>.

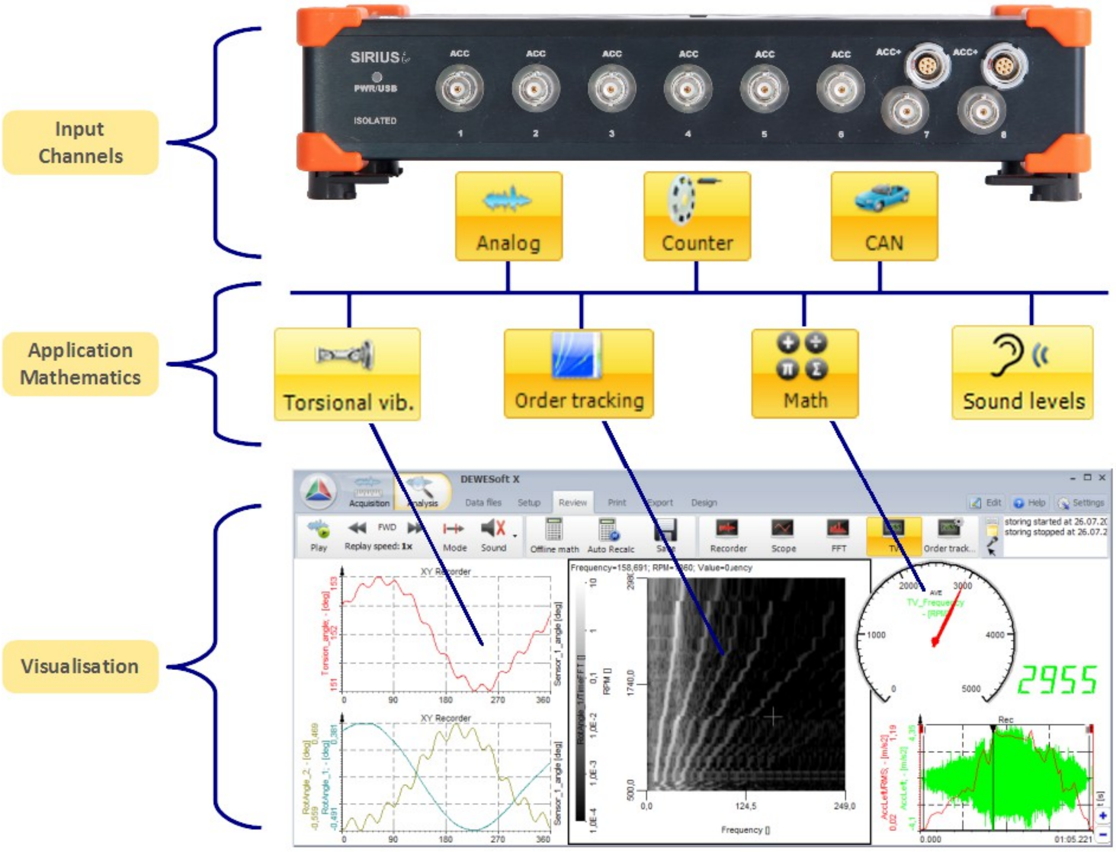


Usually this must not be done manually, since the license is already stored on your Dewesoft instrument.

Just click on the “Auto Detect” button and all options will be detected and enabled automatically.

2.3 Basic operating concept

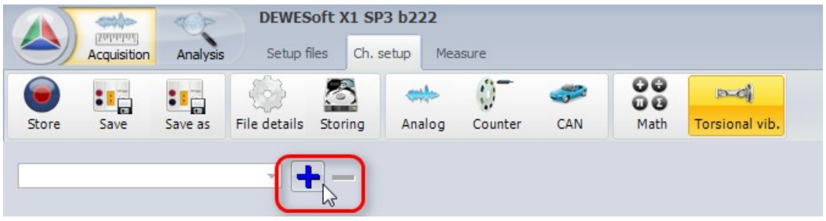
The Torsional vibration module inside DEWESoft™ is just one out of several other application modules which offers dedicated mathematics and dedicated visual controls like angle based XY-diagram.



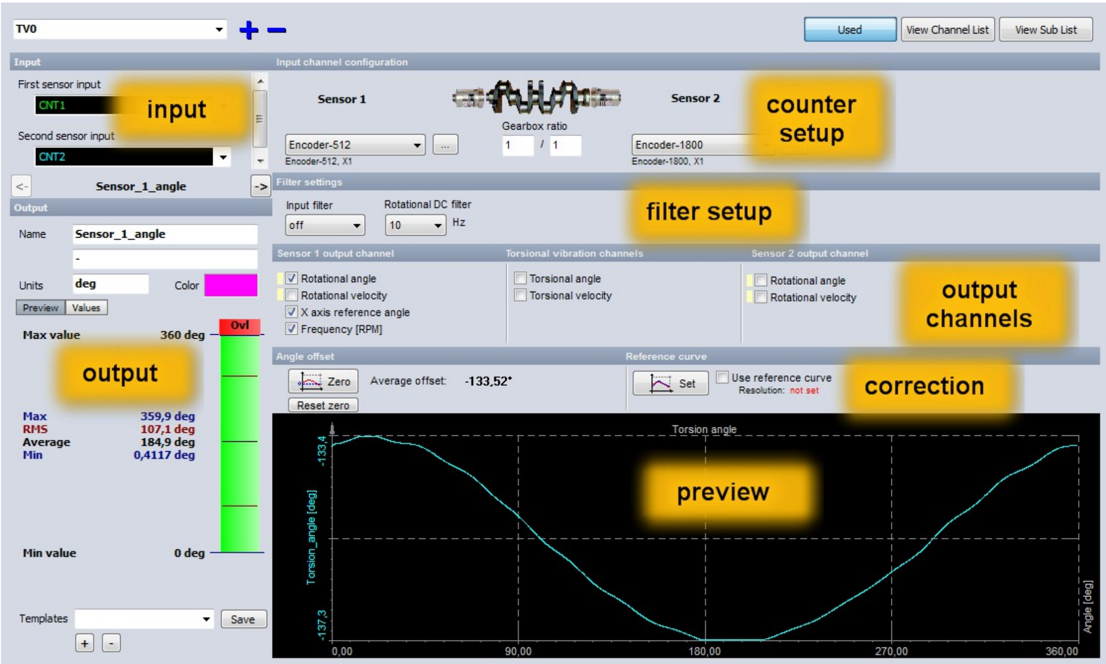
EXAMPLE	
	You can use the output channels of the Torsional vibration module as an input for the Ordertracking module, and also apply additional mathematics on it.

2.4 General setup

In the first step we add one module with the + button:



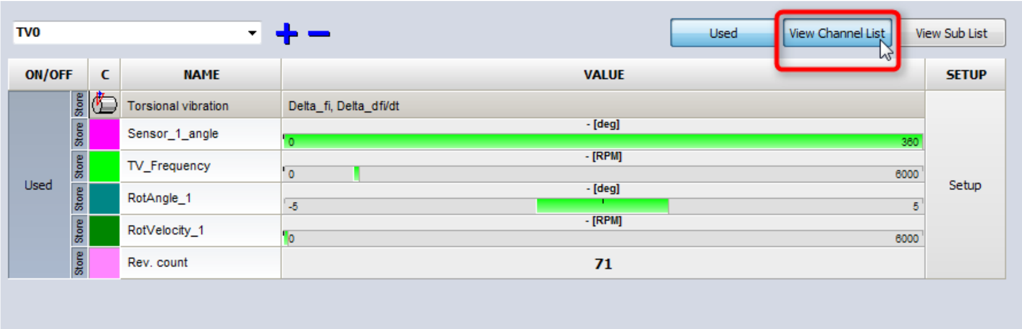
The input mask of the TV module is split into following sections:



- input: define the counter channels for input (e.g. CNT1, CNT2)
- counter setup: define type of angle sensor (e.g. Enc-512, CDM-360), and select ratio, if gearing used
- filter setup: specify glitch filter and rotational filter
- output channels: select which calculations to be done, e.g. rotational velocity, torsional angle...
- correction: compensate constant angle offset, uncentered mounting, sensor errors
- output: preview of output channels / switch through with the arrow buttons
- preview: preview of torsional angle

HINT	There is no need to configure the Counter inputs separately in the Counter setup, all the settings are done out of the Torsional vibration module. The setup of the Counters is done out of the Torsional vibration module. Used Counters will be locked (greyed out) in Counter setup.

Switch to “View Channel List” on the right upper corner to see a list of the calculated output channels.

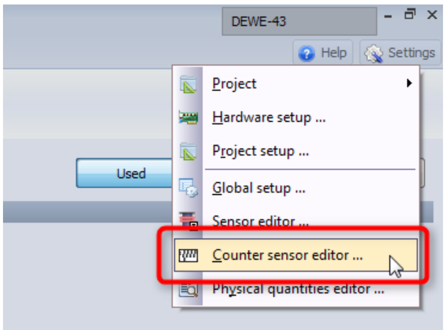


It is important to know that we actually have two different parameters that can be measured with the torsional vibration module: **rotational vibration** and **torsional vibration.**

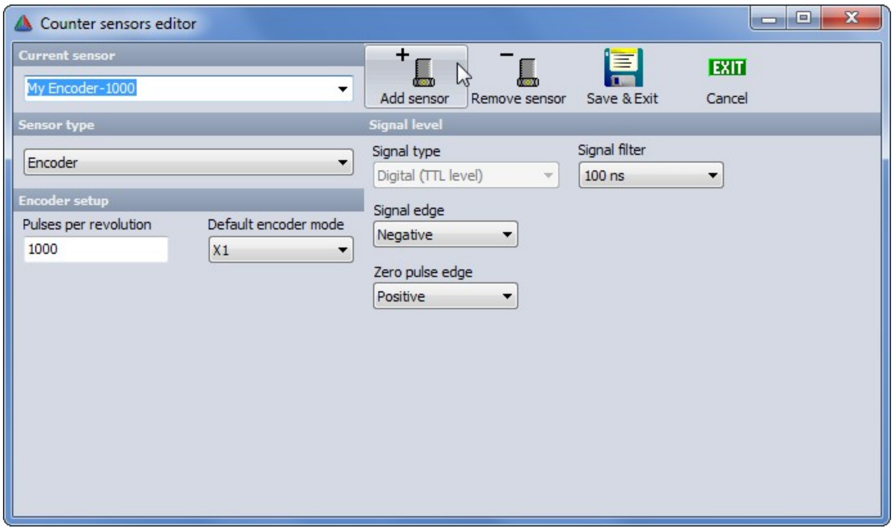
2.5 Counter Sensor Editor

There are some typical sensors predefined. However, if your type is not listed, you can define your own sensor in the Counter Sensor Editor. Note, that for Torsional Vibration module the sensor has to be either Encoder or CDM type.

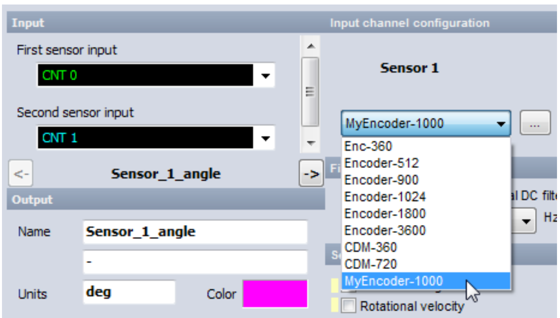
Go to Settings → Counter Sensor Editor...



… and click on “Add sensor” first, then enter a name, and set all other parameters. Depending on the sensor different parameters are available. When finished, click “Save&Exit”.



Now the sensor can be accessed from the dropdown menu of the Torsional vibration module.

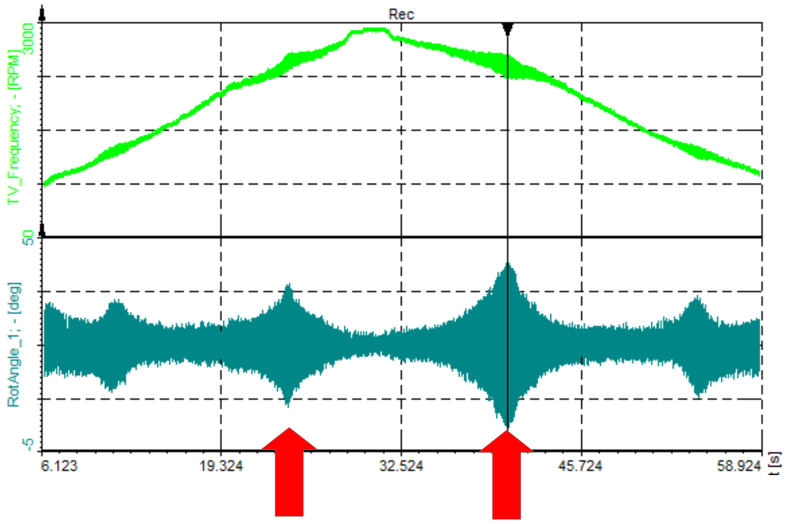


HINT	You can press <F1> in any menu in DEWESoft and the help for the specific topic will open.

3 Rotational Vibration

3.1 RV Introduction

Rotational vibration is simply the dynamic deviation of the rotation speed. If we measure the rotation speed of the shaft with high precision, we will notice that we get a high deviation of rotation speed in some regions of the run up. This is caused by the angular vibration crossing the angular natural frequency of the shaft. It is calculated by cutting off the DC component of the rotation speed or rotation angle.
In the graph below we see two curves, the one above is the RPM, and the curve below shows the deviation in degrees, which is actually the rotation angle vibration. During coastdown the max. vibrations appear at the same RPM's again.



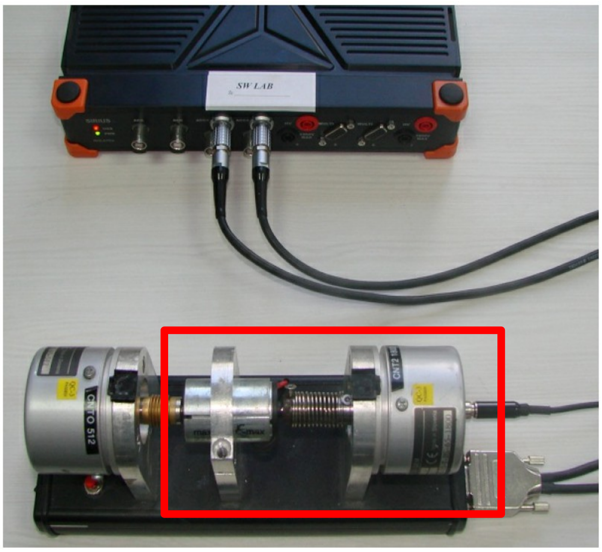
3.2 RV Setup

For our test, we take the Torsional Vibration Demo Kit, which consists of an electric motor (in the middle) and two encoders. The encoder on the left is connected with a coupling and the encoder on the right with a spring to the motor, to create high vibrations.

Because we are currently only interested in rotational vibration, we will only use the encoder on the right side, connected with the spring (see red box).

Connect the Encoder to the DEWESoft instrument on a Counter input.

As mentioned, there is nothing to be setup in the analog or counter channels setup. Let's just go to the Torsional vibration module, where we first add a new module by clicking the + button. Next we select the First sensor input . Since we have connected the first sensor to CNT1, we need to select it from the list. Then we define the sensor. In our case we have 1800 pulses per revolution, so we choose Encoder-1800. If the sensor used is not defined so far, we need to create it in the Counter sensor editor first (see page 10, chapter 2.5 Counter Sensor Editor)



3.2.1 Input filter

The **input filter** can be used to prevent glitches and spikes in the digital encoder pulse signal. It can be set from 100ns to 5us, the optimal setting is derived from following equation:

$$InputFilter[s] \le \frac{1}{10 \cdot \frac{RPM_{max}}{60} \cdot PulsesPerRev} \qquad \begin{array}{l} RPM_{max} \dots max\ revolutions\ per\ minute\ [min^{-1}] \\ PulsesPerRev \dots pulses\ per\ revolution\ of\ encoder \end{array}$$

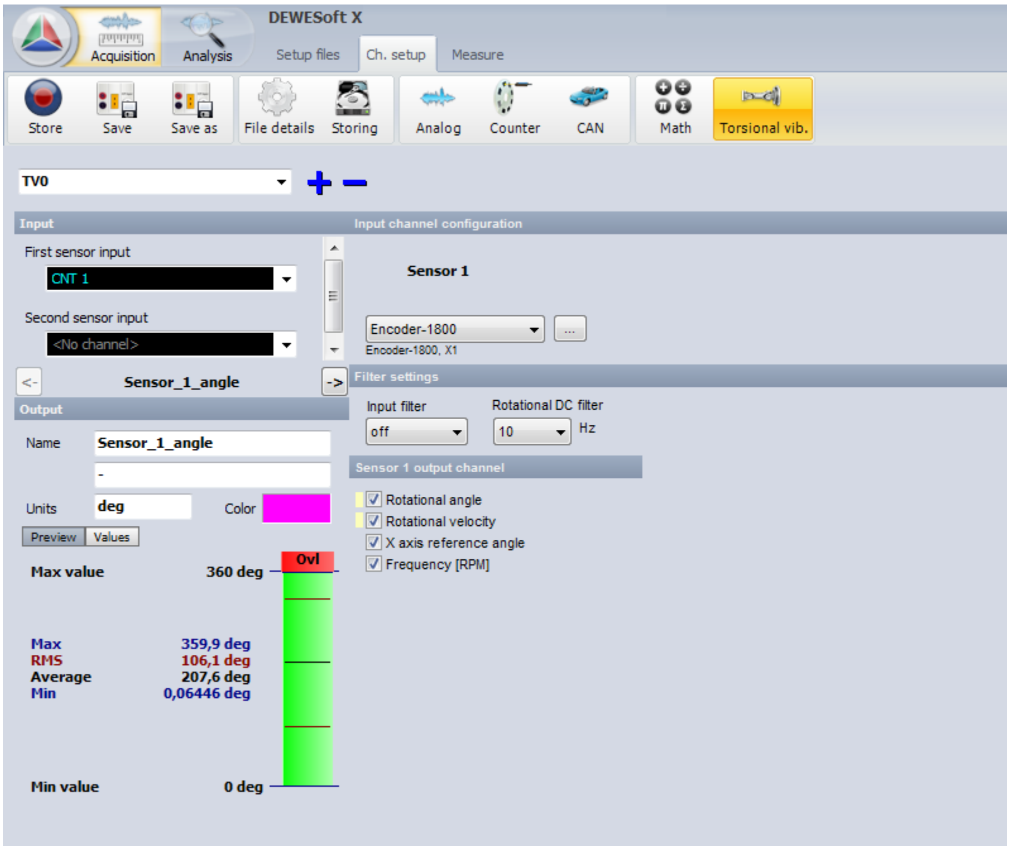
3.2.2 Rotational DC filter

The **Rotational DC filter** needs to be set to cut the DC component of the RPMs. We need to set the filter to include all wanted frequencies, but not too low, else we will have static DC deviations on the output signal. It can be set from 0.1 to 10 Hz. You have to ensure that your lowest RPM is not filtered out!

$$RotDCFilter[Hz] \le \frac{RPM_{min}}{60} \qquad RPM_{min} \dots min\ revolutions\ per\ minute\ [min^{-1}]$$

A 10 Hz filter for example would mean, frequencies below 600 RPM would be suppressed.

3.2.3 Output channels

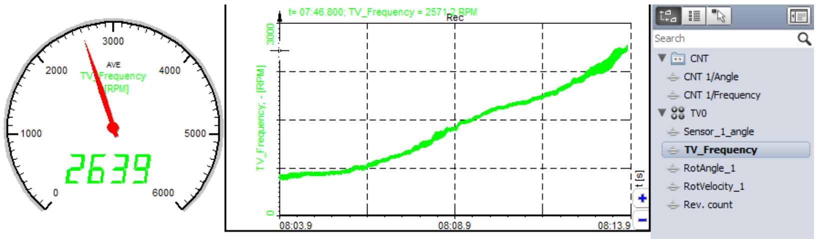


The output channels are

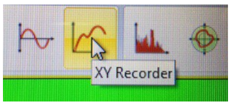
- Rotational angle (filtered angle value of vibration)
- Rotational velocity (filtered velocity vibration value)
- X axis reference angle (the reference angle, which is always from 0 to 360 and can be used as a reference in angle based xy diagrams)
- Frequency, in RPM unit

3.3 RV Measurement

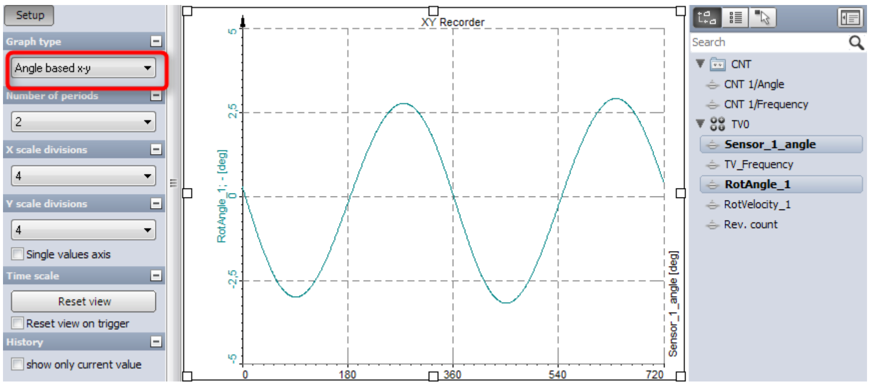
When you switch to measure mode, the calculated channels of the TV module are shown in the channel selector on the right side. First idea would be to select the TV_Frequency channel and display in analog/digital meter or a recorder.



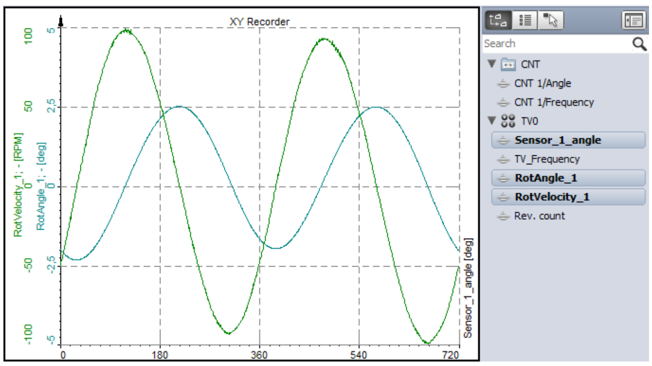
The Sensor_1_angle is the reference angle and can be used for **angle-based display** of XY recorder.Add a XY recorder and click on Sensor_1_angle first (=x axis), then on RotAngle_1 (=y axis). Then set the recorder to “Angle based x-y” in the properties on the left side. Select e.g. 2 periods to be displayed. This xy recorder now displays the rotational angle of the current revolution. It is like a scope, but with an angle reference instead of a time reference.

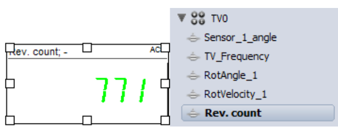


Vary the RPM and when you come close to the resonance frequency, the amplitude reaches its maximum.



In the next graph also the rotational velocity is added (first derivation on the angle), according to theory it is shifted 90 degrees.



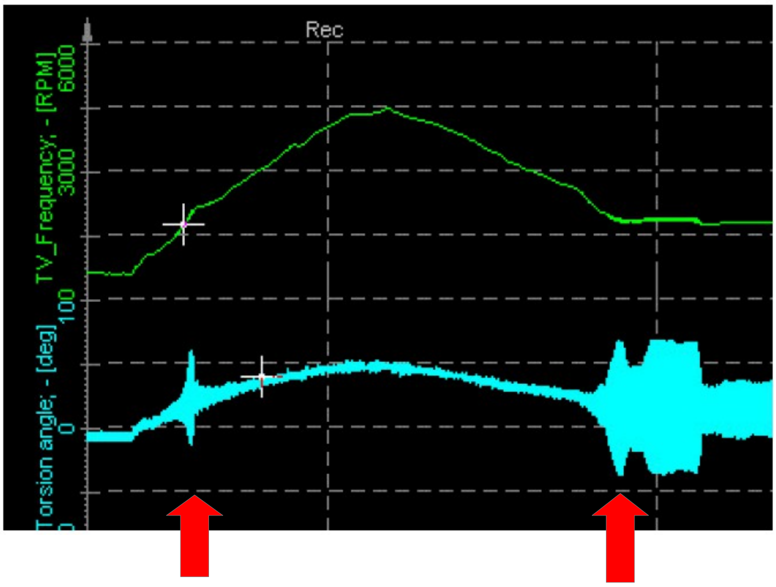
The last channel out of the module is called “Rev. count”, a revolution counter: 

4 Torsional vibration

4.1 TV Introduction

Torsional vibration is an oscillation of angular motions (twist) which occur along rotating parts, such as gear trains, crank shafts or clutches. We need two encoders to measure the torsional vibration, so the torsional vibration is actually a difference between angles of the two encoders. The torsional vibration also measures the static twist of the shaft with higher RPMs.

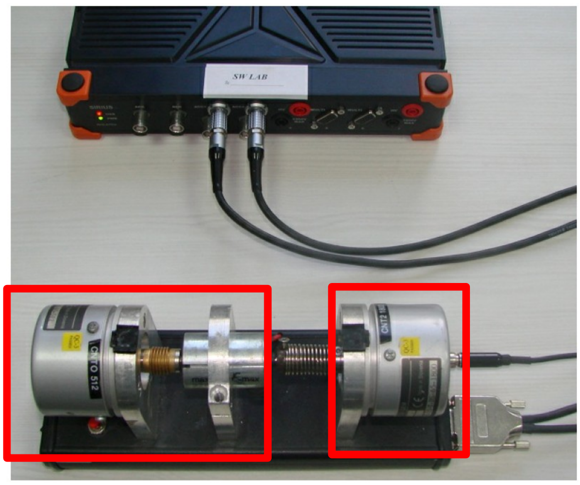
The graph below shows the run up and coast down where we can nicely see the static twist of the shaft, and when passing through the natural frequency, the angular vibration of the shaft reaches its maximum.



4.2 TV Setup

We extend the setup from the Rotational Vibrations Measurement by also connecting now the second encoder.

On the left side is an encoder with fix (coupled) connection to the motor (first red box), on the right side is another encoder (second red box). So we measure the torsion vibrations of the metal spring between.



Add a Torsional vibration module with the + button.

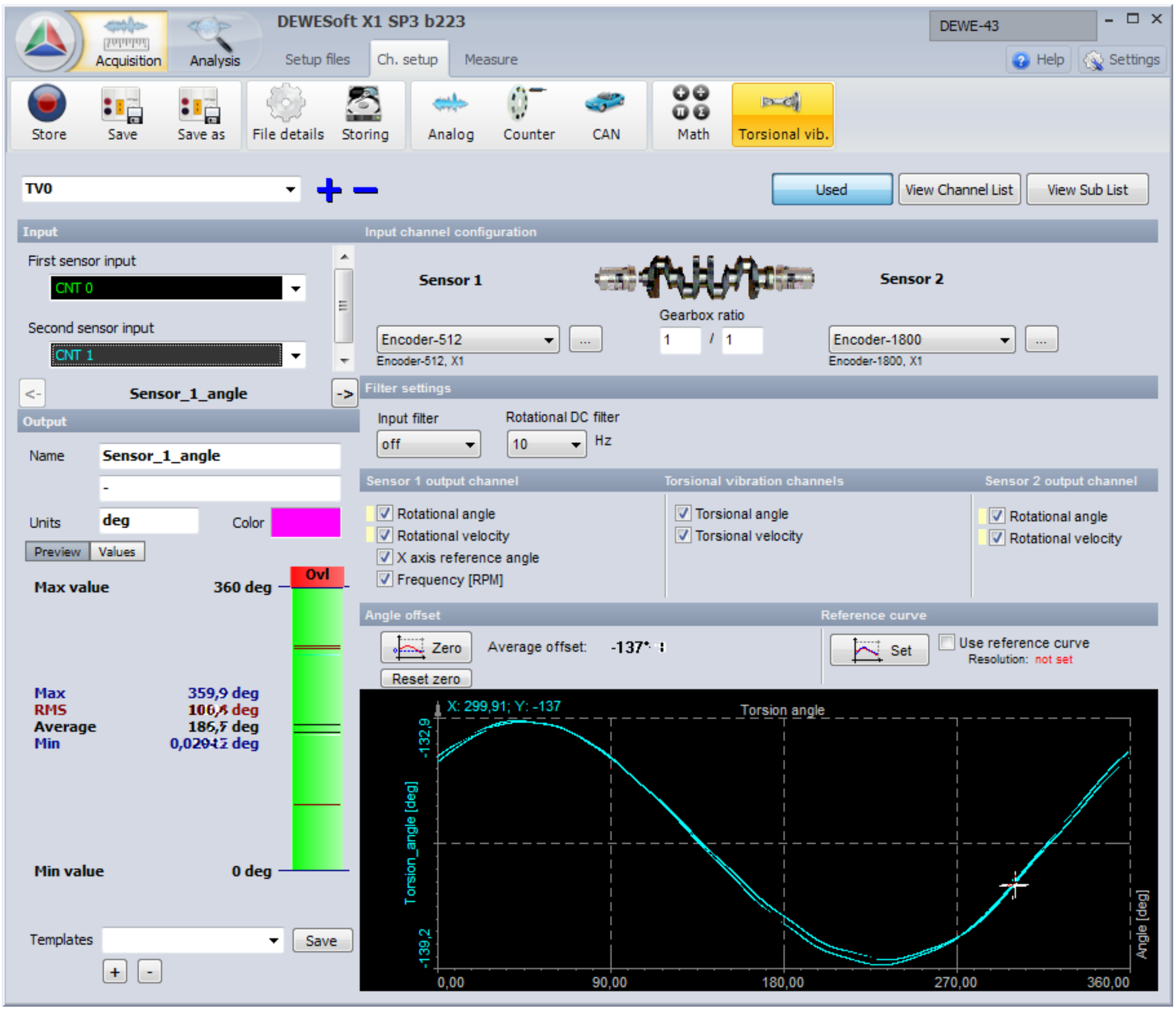
Select CNT0 as first and CNT1 as second sensor input. Then further define the encoders by selecting the correct type from the dropdowns on the right side (in our case Encoder-512 and Encoder-1800).

As already explained in the rotational vibration section, you can use the input filter for cleaning the signal from eventual glitches, and the rotational filter removes the DC offset from the difference signal.

4.2.1 Gearbox ratio

Gearbox ratio stays 1/1 in our case. This is used for measuring the torsion angle across a gearbox.

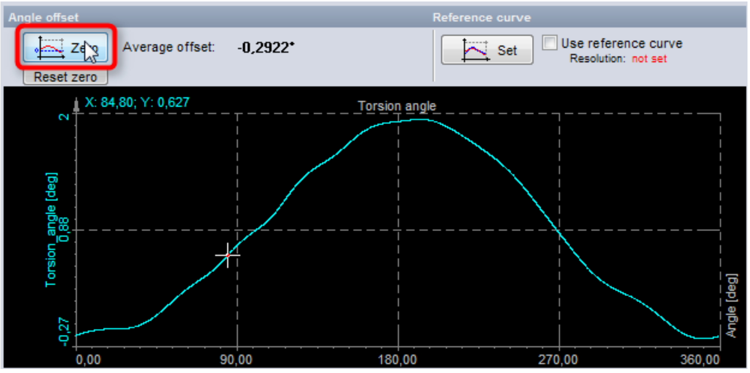
4.2.2 Output channels



- Torsional angle (dynamic torsional angle that is the angle difference from sensor 1 to sensor 2)
- Torsional velocity (difference in angular velocity from sensor 1 to sensor 2)
- Sensor 1 Rotational angle
- Sensor 2 Rotational angle
- Sensor 1 Rotational velocity
- Sensor 2 Rotational velocity
- X axis reference angle (the reference angle, which is always from 0 to 360 and can be used as a reference in angle based xy diagrams)
- Frequency, in RPM unit

4.2.3 Angle offset

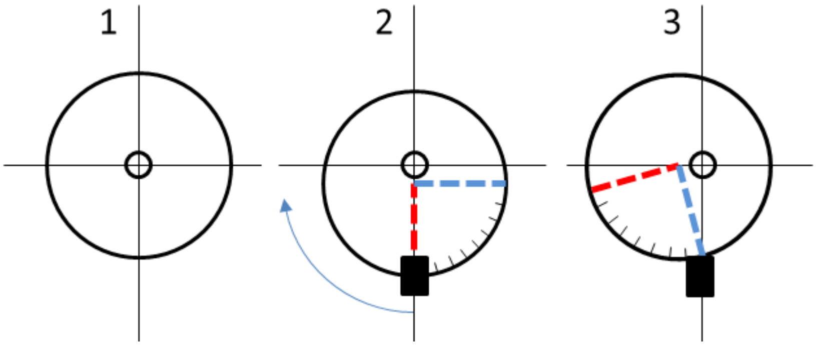
In the section “Angle offset” you see the angular difference between the two sensors (-137°). Click on “**Zero**” to **remove this static offset**. The current average value of the signal will be subtracted. Then click on the y axis to auto-scale the signal. It is now approximately 0.



4.2.4 Reference curve

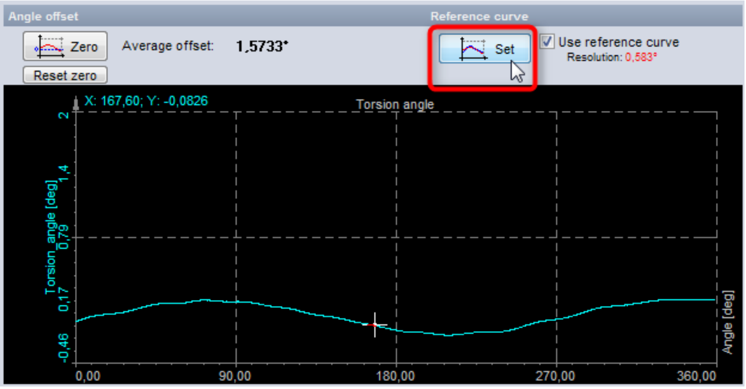
Now there is also an option how to **compensate uncentered mounting** and **unsteady pulses from encoder.**

Centered mounting is very important. On the first picture (1) there is no problem, the disk is mounted perfectly. However in real life, uncentered mounting like in picture (2) will appear. Let's draw on the disk a red line on 0 degree and a blue line on 90 degree position. When the disk is turned, the sensor (black box) will count the pulses and after a certain number detect the 90 degree position. But if you look at the disk now, it is far from 90 degrees!



Think of it rotating, then a constant sine wave will be generated additionally to the rotational vibrations. This can be compensated in DEWESoft using the reference curve.

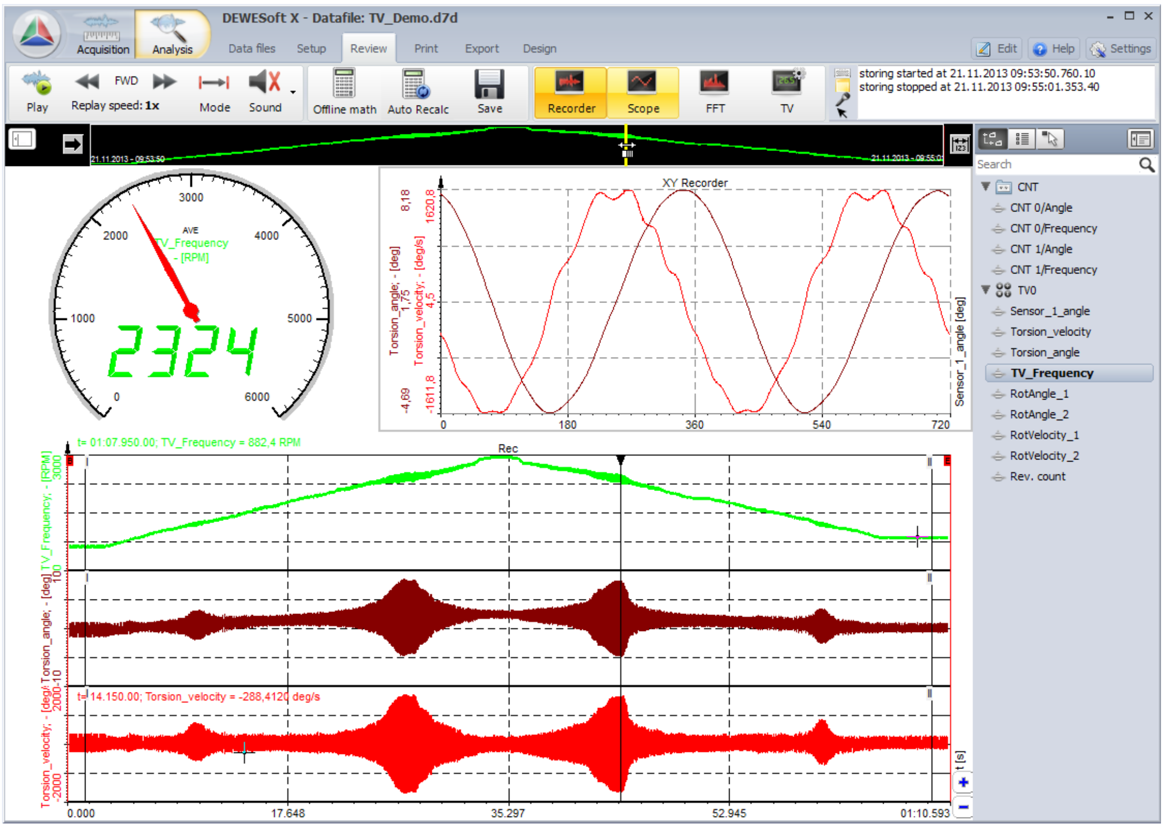
However, therefore it is required that the load must be removed from the engine! It must be free-run. Otherwise you would also cancel out vibrations you want to analyze. When the the machine is running, press the “Set” button.



The current curve is now recorded over one revolution as a reference. After that the line is much more flat.

4.3 TV Measurement

Below you see an example setup screen with some typical instruments. Similar to the rotational vibration setup we can use the XY recorder to display the result angle-based. After the runup / coastdown you see typical resonances and can analyze the data further.

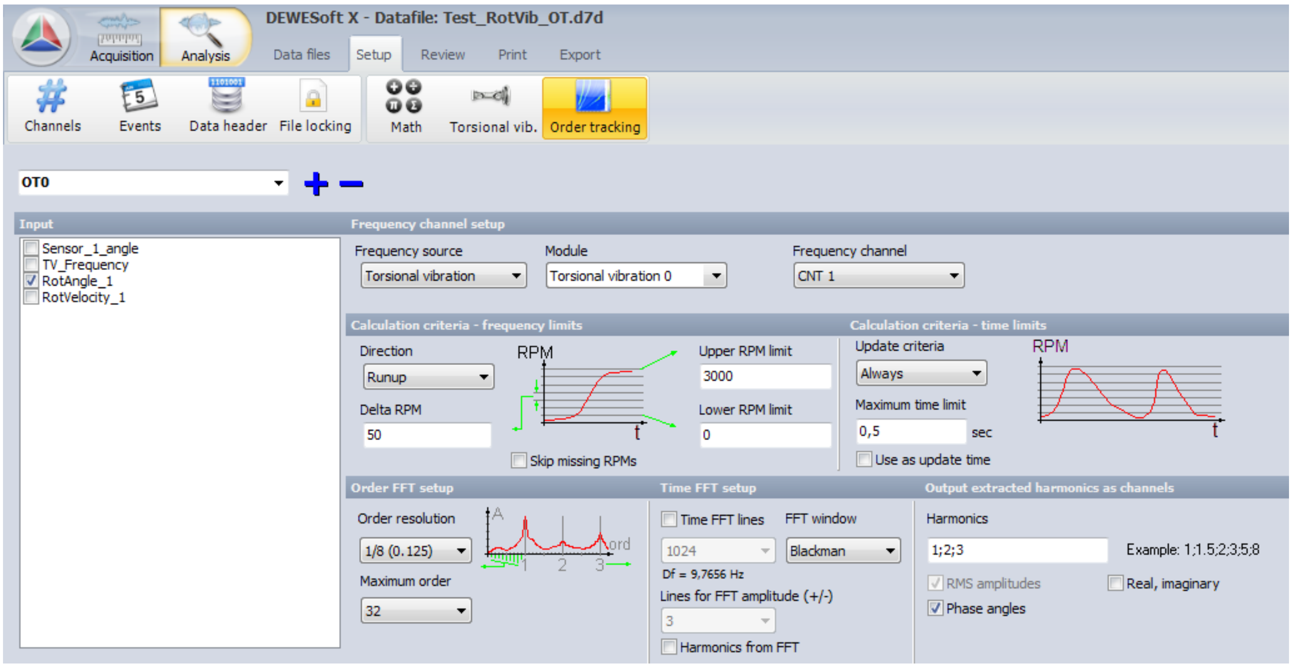


5 Advanced analysis and export

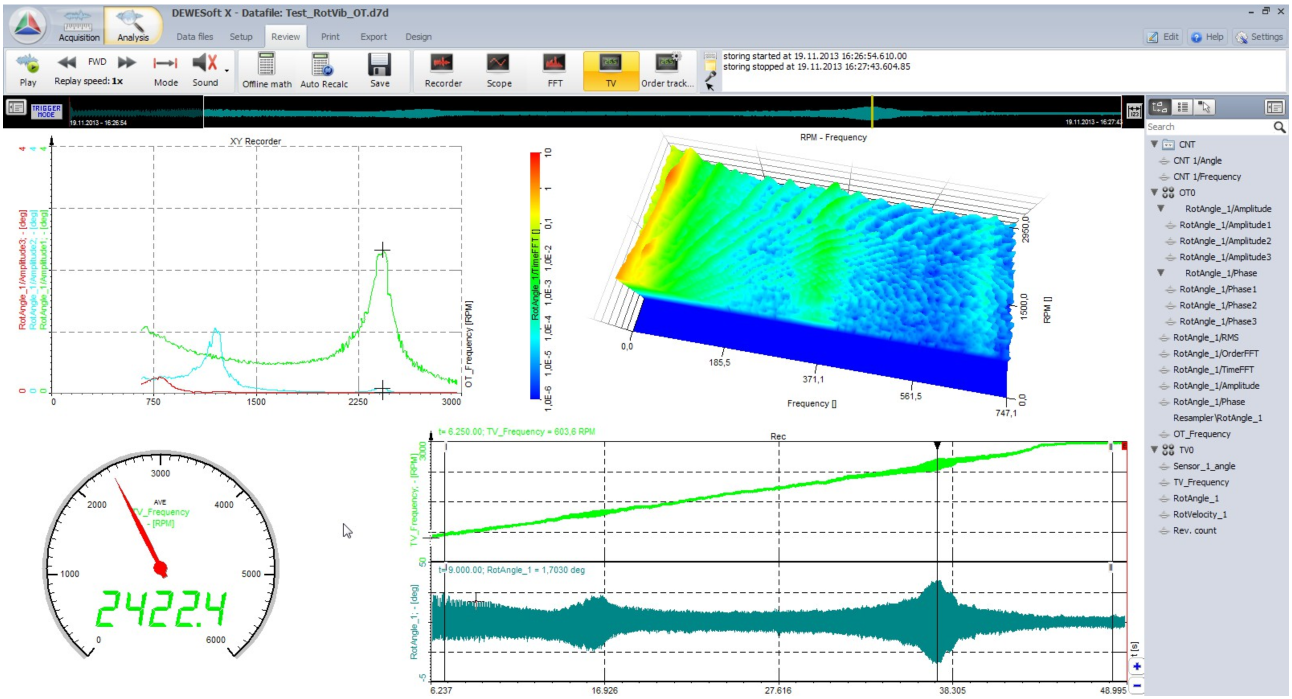
5.1 Order extraction

Let us look a little bit further and extend the functions by adding the Order Tracking option.

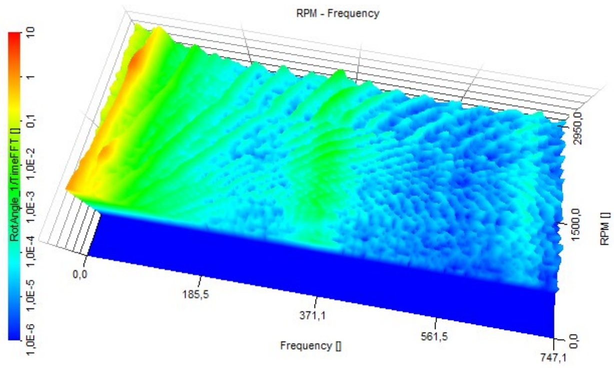
Usually it is included in the DSA package, we can use it to extract the orders of the torsional / rotational vibrations.

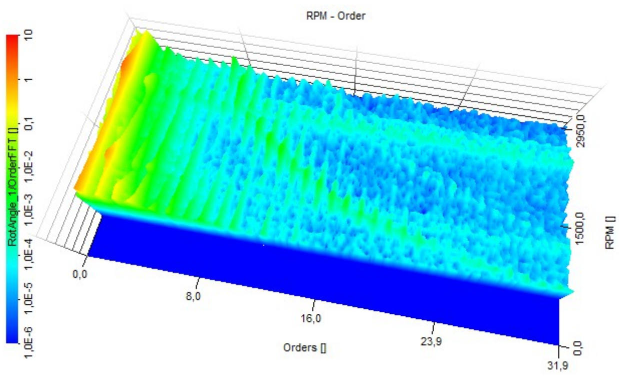


Add an Ordertracking module. For the frequency source we need to define the Torsional vibration module and the module created before. Define the Upper and Lower RPM limit. This is used to reserve the memory for waterfall FFT. The waterfall will be drawn from the lower to the upper limit in the Delta RPM step . In this case, we will have (3000-0) / 50 = 60 steps of waterfall. We choose to extract the first three orders by entering “1;2;3” in the Harmonics field. The yellow field indicates that you have to press enter to overtake the values.



With the 3D waterfall plot we can get a better picture of the situation. Plot frequency against RPM, or Orders against RPM. On the left picture one can easily seperate into frequencies related and not-related to RPM.

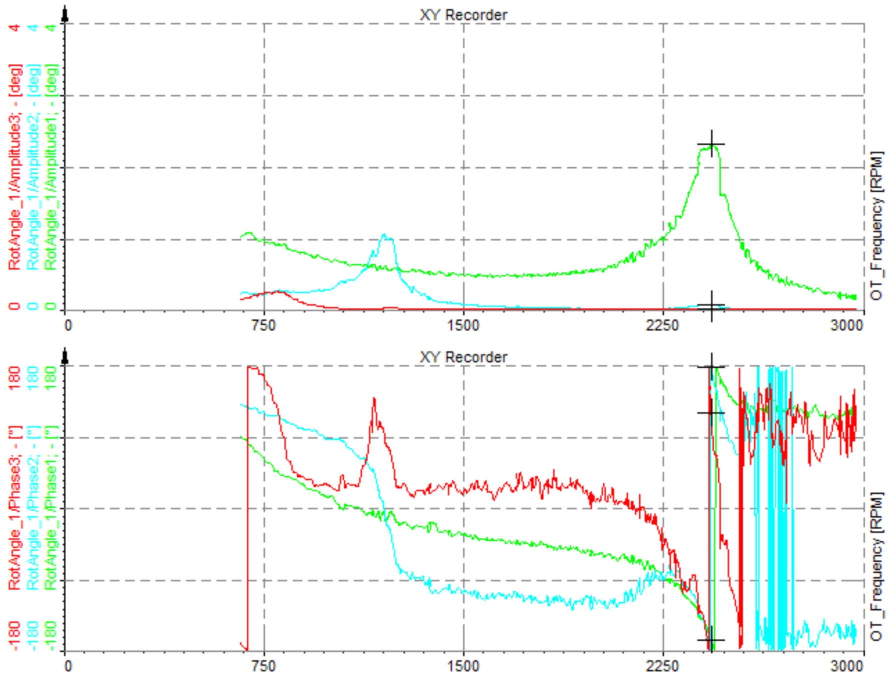




Furthermore the amplitudes / phases (or even real and imaginary part) of the Orders can be plot against the frequency.

Again, take the XY recorder, but now set graph type to “Single x axis” to get a Bode plot.

Here you see the first harmonic (green line) with its maximum around 2400 RPM, matching nicely to the previous measurements. Turning of the phase also indicates resonance.

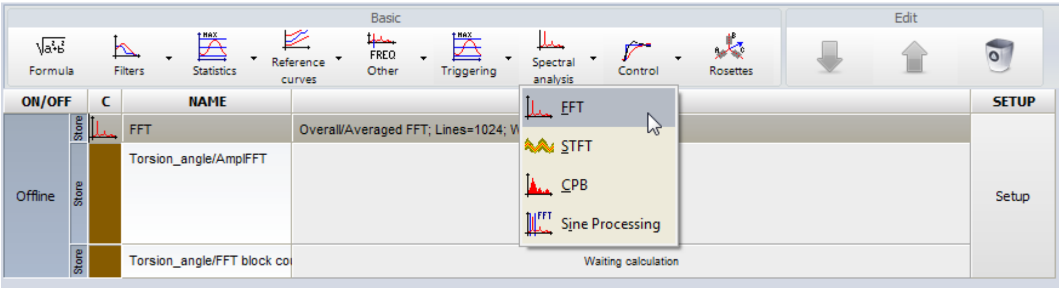


HINT	Settings can also be added / modified “offline” (=after measurement) on the datafile.

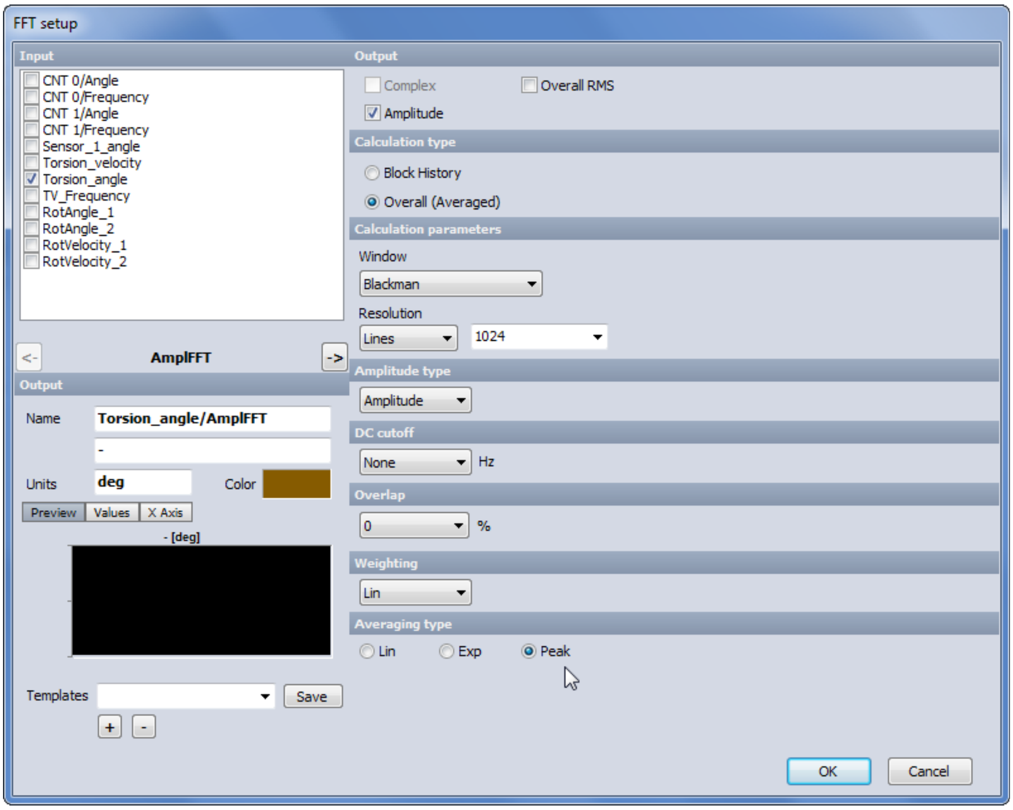
5.2 FFT peak calculation

One of the standard measurements is, to do e.g. the run up of the machine, and then calculate the max amplitude over the FFT.

Add a FFT function from the “Spectral analysis” section in math.



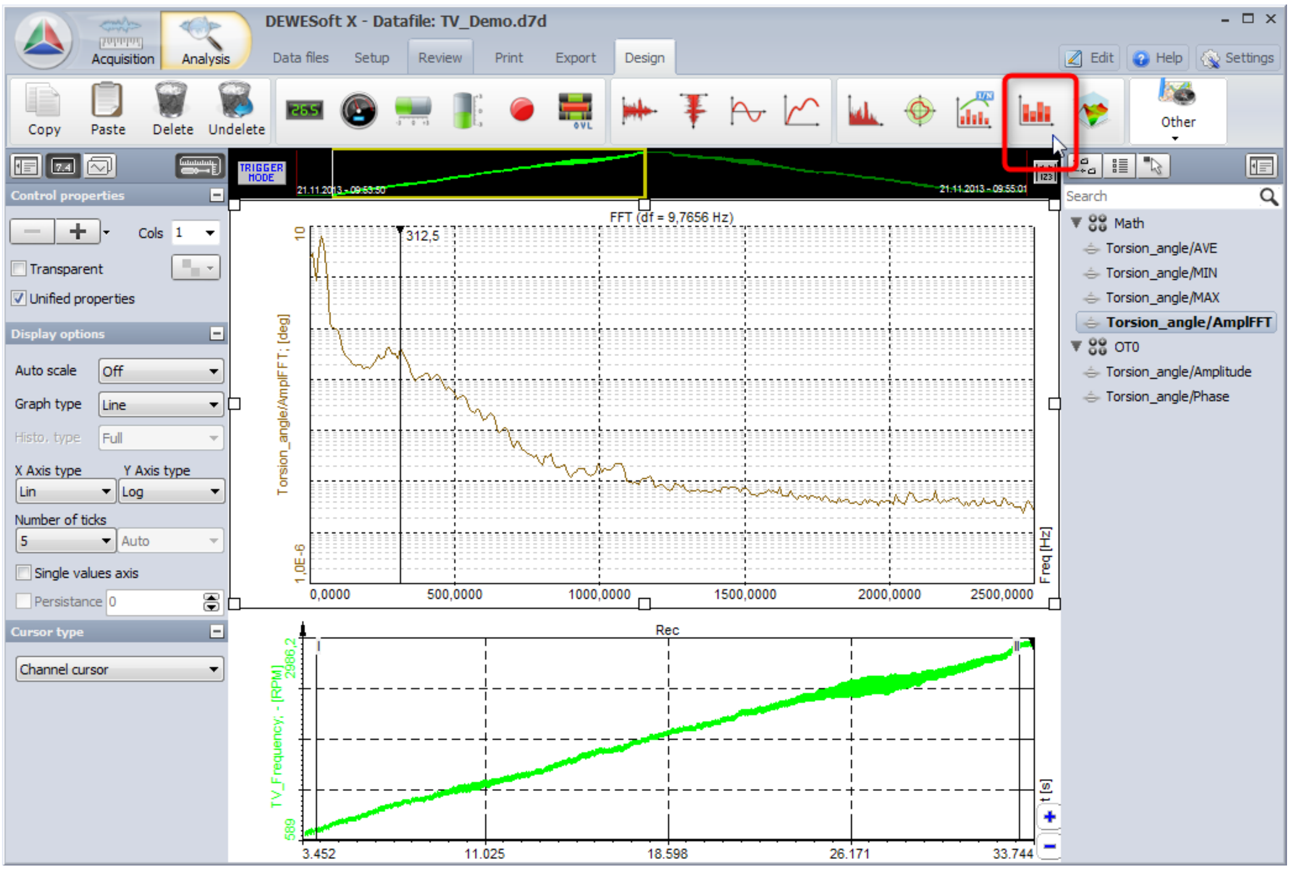
Then select the input channel, here for example Torsion_angle. Set to amplitude, Overall, and averaging type peak.



Here is an example, done offline on a datafile (of course you also can do it online, during measurement). A section has been selected in the recorder instrument below (green line) to only analyze the runup of the machine.

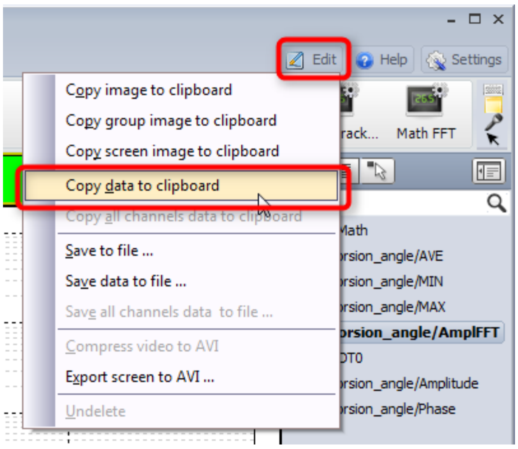
Then a 2D graph was added (see instrument bar, red box) and the AmplFFT math channel assigned.

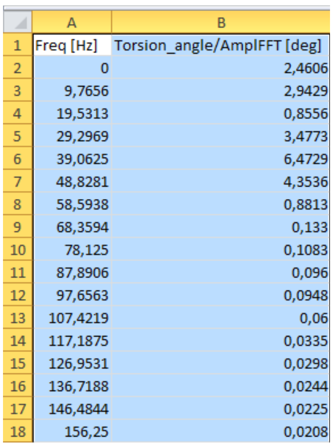
Y axis type can be set to logarithmic in the 2D graph properties (left side) for convenience.



You can do the standard export, or just click on the 2D instrument, and use “Edit” → “Copy data to clipboard”.

Pasting, e.g. into Excel gives following result:



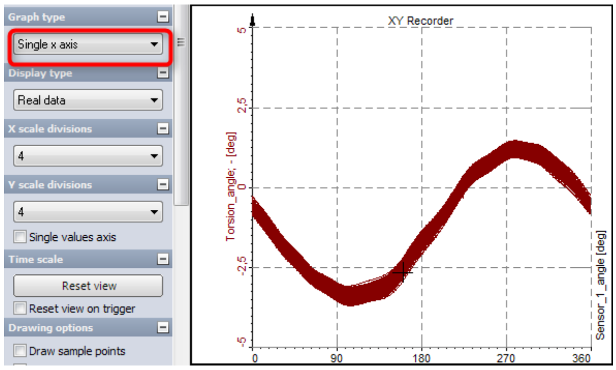


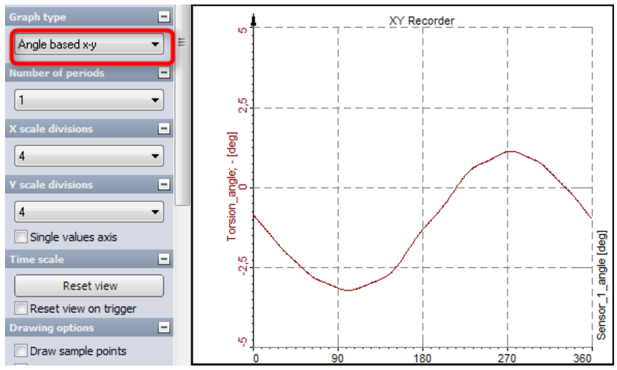
	A	B
1	Freq [Hz]	Torsion_angle/AmplFFT [deg]
2	0	2,4606
3	9,7656	2,9429
4	19,5313	0,8556
5	29,2969	3,4773
6	39,0625	6,4729
7	48,8281	4,3536
8	58,5938	0,8813
9	68,3594	0,133
10	78,125	0,1083
11	87,8906	0,096
12	97,6563	0,0948
13	107,4219	0,06
14	117,1875	0,0335
15	126,9531	0,0298
16	136,7188	0,0244
17	146,4844	0,0225
18	156,25	0,0208

5.3 Angle-based data export

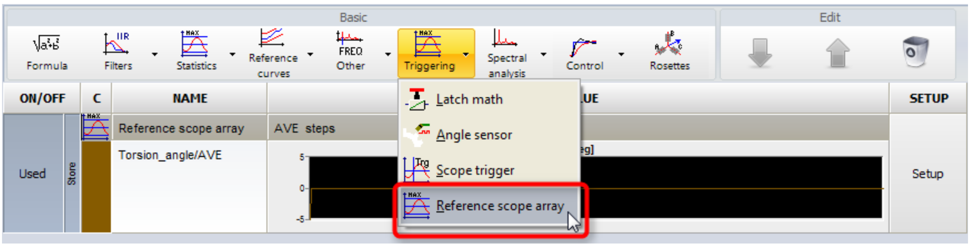
The angle-based display of measurement data is often very useful. In the XY recorder you assign the reference angle “Sensor_1_angle” to the x axis; then set the view either to

- **Angle-based xy**: working like a scope, see the current cycle
- **Single x axis**: see all cycles layed over each other (“persistence mode”), easy to see min/max over all cycles; persistence can be adjusted with the Pretime limit in the properties

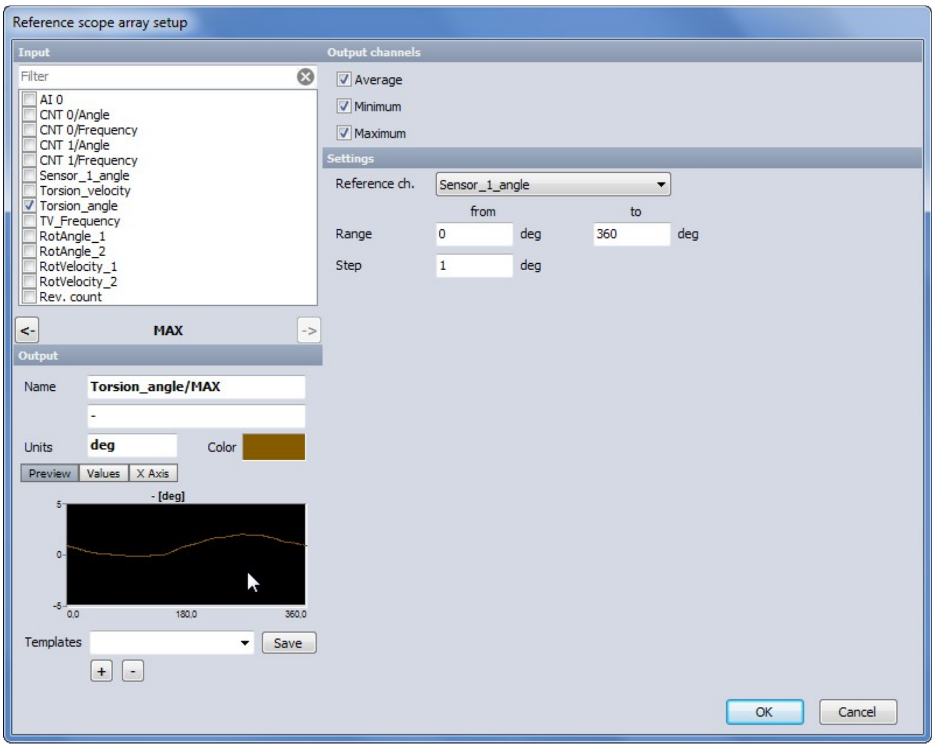




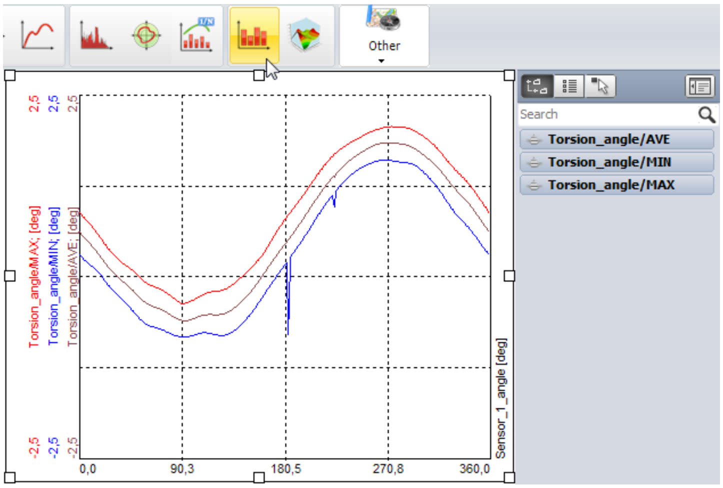
Now, how is it possible to export this cycle-based data? Go to Math and add a “Reference scope array”.



With this great tool DEWESoft arranges the input data, e.g. “Torsion_angle” over the “Sensor_1_angle” in a matrix by resampling the values to the angle-base, you also can select resolution, in this example we just use 1 degree. The output data is MIN, MAX and AVG over all cycles.



For displaying the matrix data you have to use a different visual instrument, the 2D graph. Then you can assign the AVE, MIN and MAX channels from the Math function.



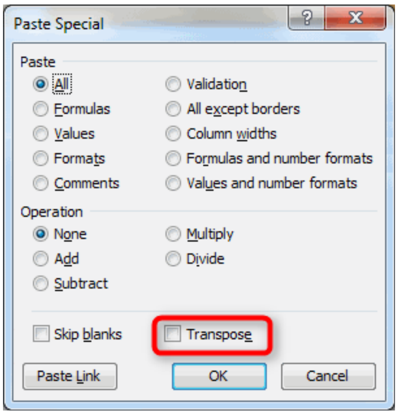
Store a datafile, afterwards in the Export section only select the 3 matrix channels (in order that data has the same format):

13	No	Math 0 (Torsional vibrati…	20000	Scalar	RotVelocity_2
14	No	Math 0 (Torsional vibrati…	65,9	Scalar	Rev. count
15	Yes	Math 3 (Reference scop…	single	Vector (361)	Torsion_angle/AVE
16	Yes	Math 3 (Reference scop…	single	Vector (361)	Torsion_angle/MIN
17	Yes	Math 3 (Reference scop…	single	Vector (361)	Torsion_angle/MAX

Here we have done the export to Excel, instead of the time axis, we have angle-based data.

	A	B	C	D	E	F	G	H		MU	MV	MW	MX	MY
1	Sensor_1_angle	deg	0	1	2	3	4		55	356	357	358	359	360
2	Torsion_angle/AVE	deg	0,691408	0,675741	0,655573	0,637096	0,617458	0,599	445	0,784162	0,761108	0,738833	0,718306	0,702214
3	Torsion_angle/MIN	deg	0,464674	0,454879	0,436415	0,419164	0,410838	0,39	4133	0,540239	0,528965	0,506269	0,484947	0,475034
4	Torsion_angle/MAX	deg	0,8667	0,856126	0,834045	0,812448	0,802175	0,	977694	0,951462	0,938873	0,914317	0,890305	0,863698
5														
6														

If you copy the data, then use the “paste special...” function in Excel, you can “Transpose” columns and rows automatically and get the angle from top down instead of left to right.



8	Sensor_1_angle	Torsion_angle/AVE	Torsion_angle/MIN	Torsion_angle/MAX
9	deg	deg	deg	deg
10	0	0,69140786	0,46467373	0,8666997
11	1	0,67574066	0,45487937	0,85612589
12	2	0,65557349	0,43641457	0,83404487
13	3	0,63709605	0,41916421	0,8124482
14	4	0,61745846	0,4108375	0,80217475
15	5	0,5993107	0,39006466	0,78169417
16	6	0,58001268	0,37931737	0,76170814
17	7	0,56014401	0,35742941	0,75193626
18	8	0,54378361	0,33580011	0,73214692
19	9	0,5250833	0,31420895	0,71221167
20	10	0,50554281	0,30327067	0,69204921
21	11	0,48762649	0,28079492	0,68180281

Selective export:

Use the recorder instrument to zoom into a section of your datafile in DEWESoft (position both white cursors I and II and click between them),then the calculation and export is only done over the selected data.

6 Measurement accuracy

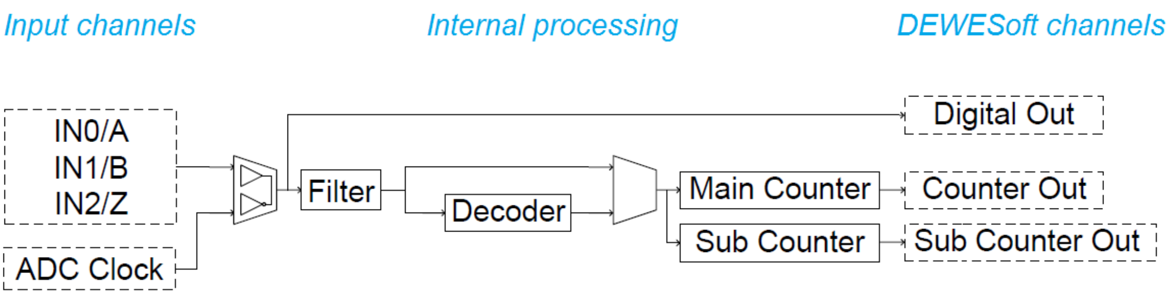
6.1 Error sources

The overall error of the measurement has to be split up into errors from the sensor and the counter measurement uncertainty. Usually the sensor errors make the major amount.

6.2 Counter accuracy

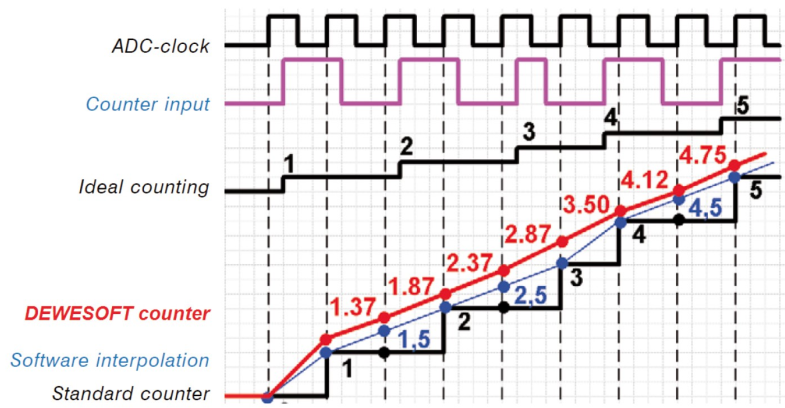
6.2.1 Counter architecture

To understand how the angle resolution is determined, it is at first important to understand the internal architecture of the Dewesoft Counters. A combination of main and sub counter is used internally for getting higher precision at the frequency measurement. The main counter is running on event counting (or encoder mode). The sub counter is used for time measurement, it measures exactly the time of the input event with a resolution of 9,77 nsec (= 1 / 102,4 MHz) relative to the sample clock.At every rising edge on the Counter Source the counter value of the sub counter is stored in a register. At every Sample Clock the values of both counters are read out.



With these both measurement results not only the frequency can be calculated in a precise way. Also the event counter result can be shown in fractions because the exact time when the event occurs at the input is known. The event counting result is recalculated with interpolation to the sample point like shown in the diagram below.

Here the improvement of the measurement result is shown. While a standard counter input shows the value up to one sample delayed, the counter input of the Dewesoft instrument calculates the exact counter result at the sample point.



IMPORTANT

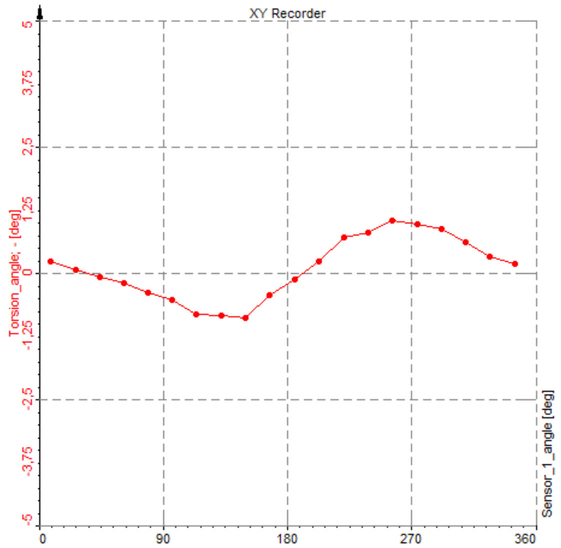
The Counter value in the software is updated with the sample rate!

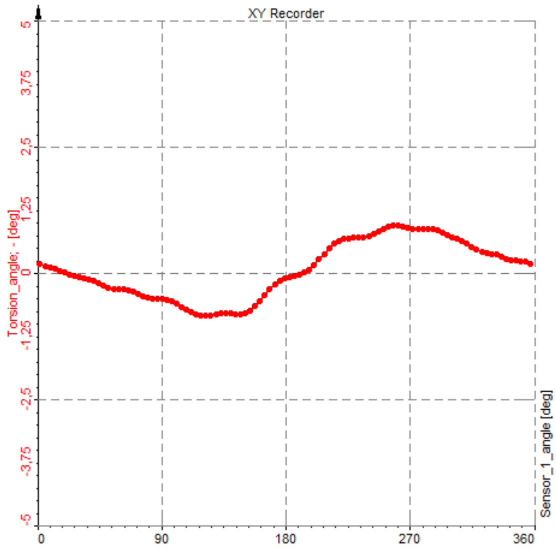
6.2.2 Angle resolution

The counter result is read out with the sample rate, therefore the same update rate applies for the calculated angle.

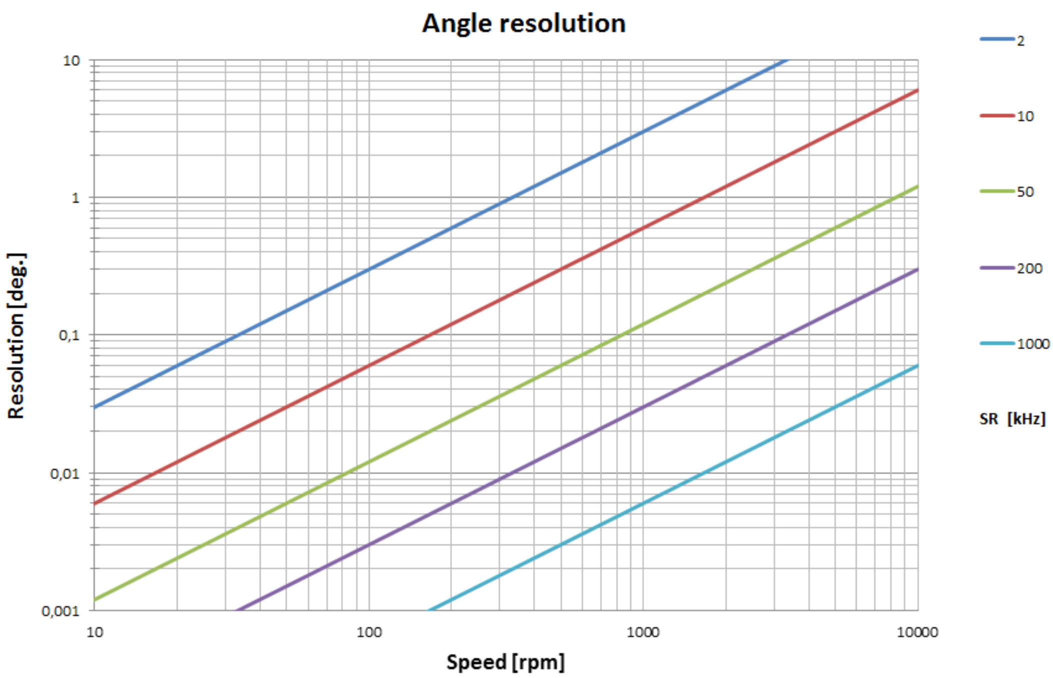
Furthermore the angle resolution depends on the rotation speed (RPM).

Below there are two angle-based 2D graphs showing the Sensor angle on the x axis at the same RPM. The option “draw sample points” was enabled. On the left side the sample rate was set to 500 Hz, on the right to 2500 Hz:





Since rotational and torsional calculations are all based on the sample rate, the angle resolution is the same.



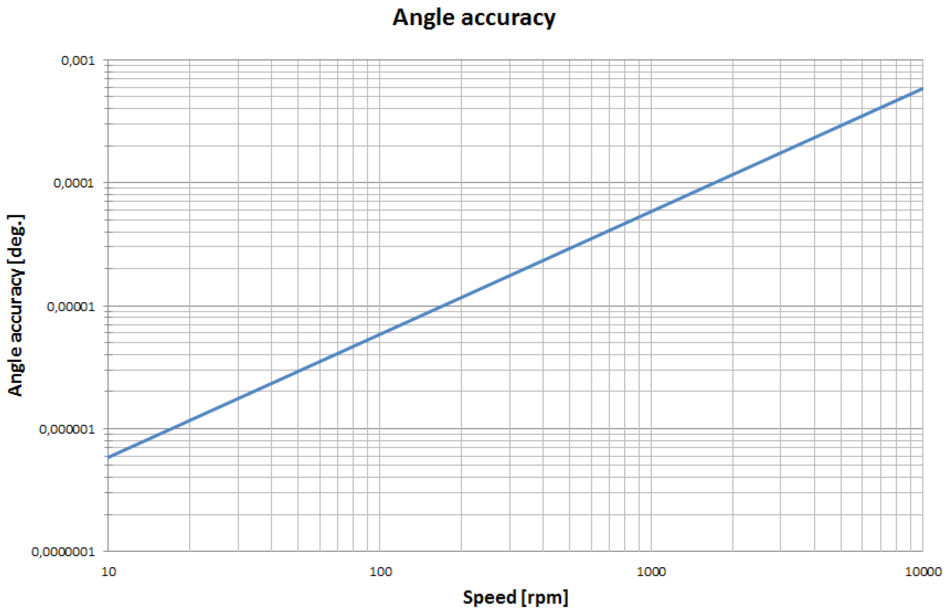
6.2.3 Angle accuracy

As the Counter is working on an internal timebase of 102.4 MHz, the angle accuracy is only depending on the rotation speed (RPM).

The following formula shows how to calculate the angle accuracy:

$$\phi_{res} = \frac{\frac{rpm}{60} * 360}{102.4 * 10^6}$$ … 102,4 MHz is the Counter Timebase

The numerator shows the angle which is passing by in one second, this is then divided by the timebase of the counter, in one second we will get 102.4 million samples.



6.2.4 Frequency accuracy

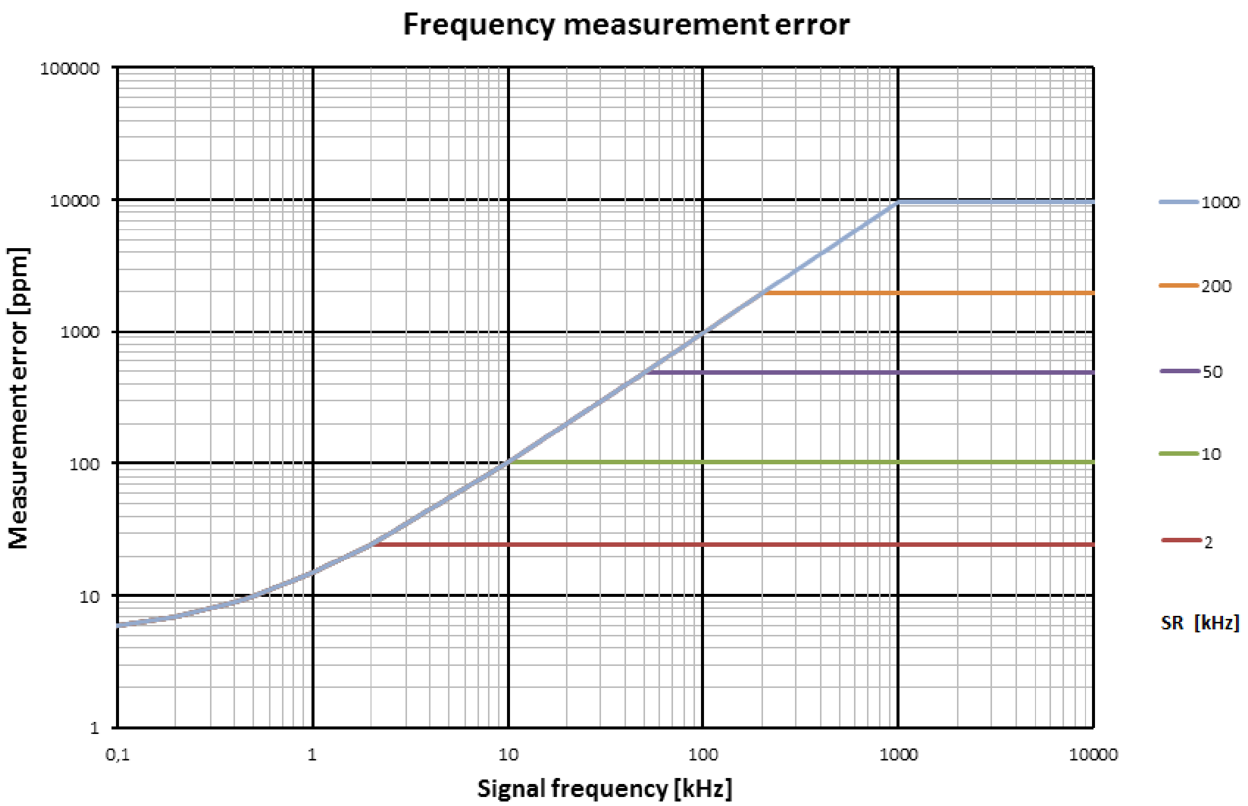
Any digital frequency measurement is based on period time measurement. The time between two edges of the input signal is “sampled” with the counter time base of 102.4Mhz. With this simple measurement method the accuracy of the measured frequency is given by ratio between the input signal frequency and the counter time base frequency:

$$f_{error} = \frac{f_{in}}{102.4 \cdot 10^6}$$

We can see, the error increases with input frequency. For example at 10MHz the accuracy goes down to 10%!

Like explained above, the advanced counter structure of Dewesoft are using two counters internal counters and the output rate is synchronous with the the acquisition rate. With this technology we can limit the maximum error to the used acquisition rate.

The illustration below shows the accuracy at different input signals between 2 kS/sec to 1000 kS/sec taking also the typical counter time base accuracy of 5 ppm in account.



6.3 Sensor accuracy

6.3.1 Non centered mounting

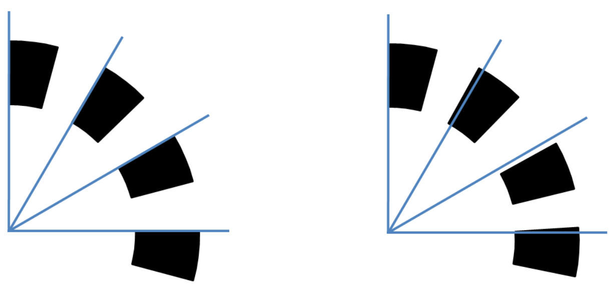
Can be corrected under certain conditions, see page 17 chapter 4.2.4 Reference curve in this document.

6.3.2 Resolution error

An additional error occurs due to mechanical tolerances of the used encoder. Depending on the encoder mode setting used (X1, X2, X4), they have influcence on the measurement.

X1 mode: For this mode only the rising edge is important. If the sensor marks are not precisely repeating at constant delta angles (have a constant “jitter”), this also can be compensated with the reference curve option

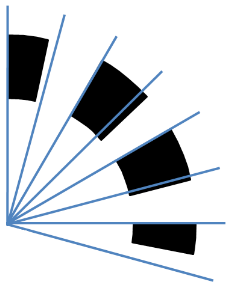
Good: Bad:



X2 mode: For X2 mode both the rising and falling edge of the first encoder track are used, which doubles the resolution. But if the duty cycle is not exactly 50%, another error is introduced.

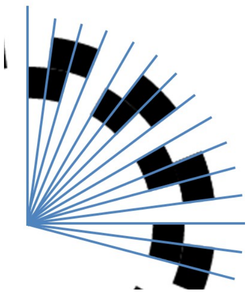
Good:

Bad:

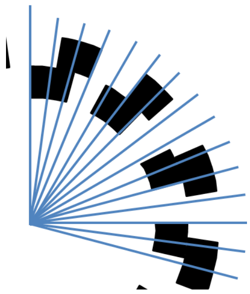


X4 mode: Both falling and rising edges of both encoder tracks are used in X4 mode to get 4 times the precision. The phase shift between the two tracks must be exactly 90° and the duty cycle 50%.

Good:



Bad:



Therefore, the higher the mode used (e.g. X4 compared to X1), the more noise will be in the measurement due to the discussed mechanical tolerances, because all effects appear together. In a manner of speaking an encoder with a high resolution (e.g. 3600 pulses), is difficult to manufacture precisely, and therefore will have more noise in X4 mode than one with lower resolution (e.g. 360 pulses) in X4 mode.

Of course, if using two encoders (as in torsional vibration), the errors are doubled.

7 Documentation version history

Revision number: 177
Last modified: Tue 03 Dec 2013, 14:55

Version	Date [dd.mm.yyyy]	Notes
1.0	*28.11.13*	☑ *initial revision*

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