Torsional vibration analysis in ArtemiS SUITE[1]

Introduction

Rotational non-uniformities of rotating systems can lead to a significant impairment of the perceived product quality, or can indicate a defect. In addition to the familiar airborne and structure-borne sound analysis, ArtemiS SUITE provides analysis functions for examining such rotational non-uniformities both in the time domain and in the frequency domain.
In order to perform a torsional vibration analysis, a revolution speed recording with a sufficient number of pulses per revolution is required, which in turn requires a sufficiently high sampling rate. For an evaluation in ArtemiS SUITE, the revolution speed can be recorded as a separate, analog channel or – as of version 7.0 – as a digital pulse channel.

Revolution speed information as separate analog channel

Revolution speed information for an analog channel can be measured, for example, with a magnetic sensor mounted radially in close proximity to a toothed wheel (see figure 1). It is recommended to choose a toothed wheel with a number of teeth that is more than twice the maximum order to be analyzed. Furthermore, the sampling rate must be high enough to record several samples per tooth.

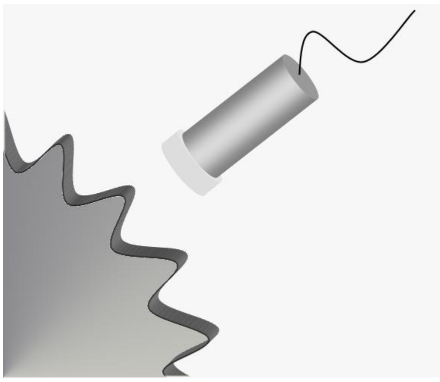


Figure 1: Schematic representation of a measurement setup for torsional vibration analysis

In order to apply the analysis functions provided by ArtemiS SUITE to such a signal, the signal must first be pre-processed. This is done in a Decoder Project using a trigger decoder. It is possible to apply the pre-processing to multiple files at once.
A measurement setup as shown in figure 1 delivers a sine-shaped signal, which is digitized and saved as an analog channel.
Figure 2 shows an example of such a signal. One period (T) of the signal corresponds to one tooth on the toothed wheel.

[1] The descriptions in this Application Note refer to version 9.2. The general procedures also apply to other versions. However, the scope of functionality and the user interface may differ.

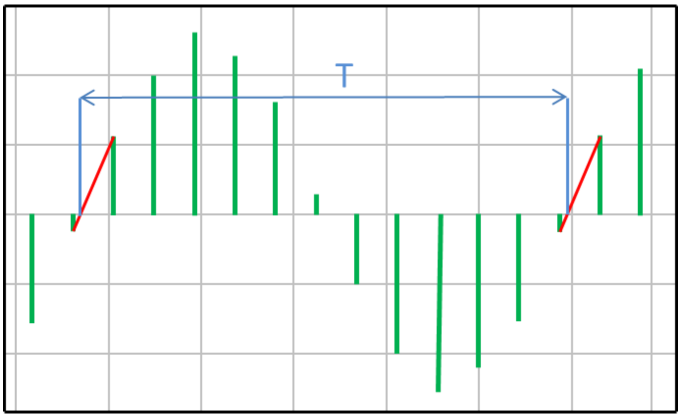


Figure 2: Schematic representation of a revolution speed signal for torsional vibration analysis

The trigger decoder scans the signal for a predefined threshold; in this example, the zero-crossing points with a rising slope. Subsequently, the exact position of the zero-crossing is determined by interpolation between the samples (see figure 2). The momentary revolution speed can then be calculated very precisely from the period T between two zero-crossings and the number of teeth on the toothed wheel:

$$\text{momentary revolutions per minute [RPM]} = \frac{1\text{min}}{\text{T[min]} \cdot \text{number of theeth on the toothed wheel}}$$

The number of teeth must be entered in the sensor definition in the Channel Editor (see section “Proceeding and general notes”).

Revolution speed information as digital pulse channel

Revolution speed information recorded as a digital pulse channel can be used for torsional vibration analysis as well. In this case, too, the signal must first be pre-processed. This is done in a Decoder Project using a pulse decoder. Again, it is also possible to pre-process multiple files at once.

If the revolution speed information is saved in the form of identical pulses rather than a digitized analog signal, the determination of the momentary revolution speed cannot be improved by interpolating the zero-crossings. Therefore, the decoding of the revolution speed is slightly less precise in this case than with the method described above.

Nevertheless, the results are very well suited for a qualitative analysis, which makes torsional vibration analysis possible even in cases where the analog method of acquiring revolution speed information cannot be used. The digital acquisition of RPM data, too, requires a sufficiently high sampling rate. This can be ensured, for example, by using the upsampling option for the pulse inputs of the HEAD*lab* recording system.

The number of pulses per revolution is specified in the sensor definition in the Channel Editor or in the HEAD Recorder (see next section).

Proceeding and general notes

A new Decoder Project can be opened via ***START*** -> ***New*** -> ***Decoder Project***. A Decoder Project contains three pools similar to those of a Pool Project.

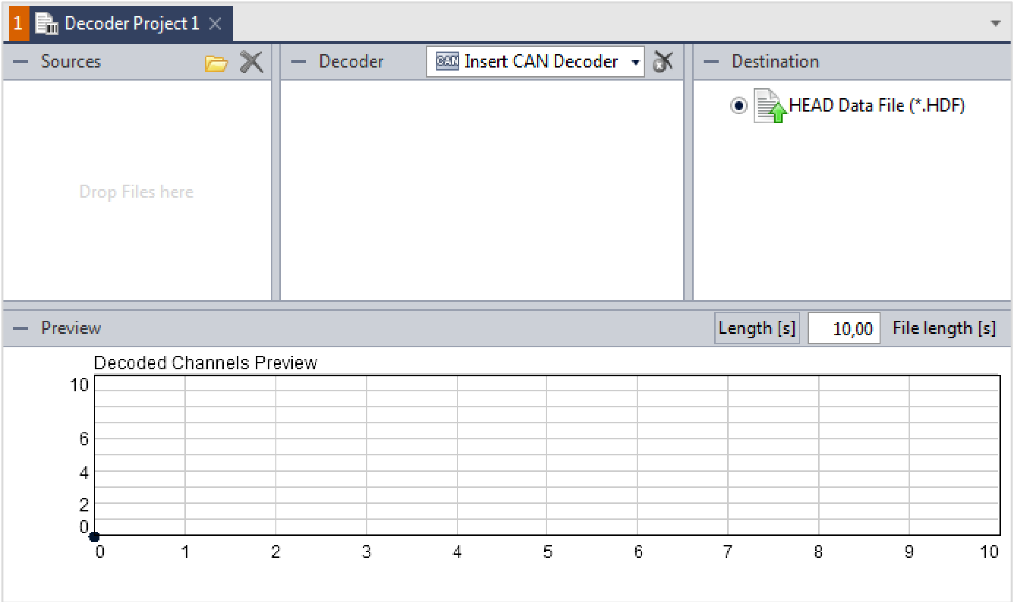


Figure 3: Newly created Decoder Project

The Source Pool on the left side is where you add the time domain signals, for which you want to perform torsional vibration analysis. In the center pool, which is comparable to the Analysis Pool of a Pool Project, you can select the decoder that suits your data.
Using the decoder, ArtemiS SUITE calculates an additional channel, in which the time domain signal of the momentary revolution speed is saved. The preview window of the Decoder Project displayed below the pools (see figure 3) allows you to check the calculated revolution speed curve in advance.
The additional channel can be saved to a new file along with the original channels. In the Destination Pool of the Decoder Project on the right side, you can specify the file format for this new file. Available export formats are HDF, ATFX, and UFF[2]. For a torsional vibration analysis, the HDF format is the best choice, since an HDF file can be directly added to a Pool Project for further analysis.
In a Decoder Project, all input signals are always active. You can also activate multiple decoders at once for a calculation.
To ensure that the decoder can determine the correct revolution speed information, the number of teeth, any gaps between teeth, etc. must be specified. To do so, open the file in the Channel Editor (right-click on the file -> ***Edit HDF with*** -> ***Channel Editor***).
If your revolution speed data is stored in an analog channel, first create a digital trigger channel based on this analog channel (***Signal Channels*** tab -> right-click on the analog channel with the revolution speed -> ***Add new Trigger Channel***). This opens a new window, where you can specify the channel name, the physical quantity and the measurement unit for the new channel. With the ***Edit Pulse Sensor Geometry*** button, you can create a new pulse sensor geometry, which specifies the required sensor information (such as the number of teeth, tooth gaps, etc.). You can also import this sensor information from your sensor library using the ***Import from Sensor Library*** button.
If your revolution speed information already exists in a digital channel, specify the required sensor information via the ***Pulse Channels*** tab -> right-click on the pulse channel with the revolution speed data -> ***Edit Pulse Sensor Geometry***.

[2] UFF export can only be used if your software license includes the Advanced Import & Export Module (ASM 23).

When all settings are made, click on ***Save Changes*** in the Channel Editor to save your configuration. Note that this will overwrite your original file.[3]
Of course, the procedure described above for creating a new trigger channel and editing the sensor information can also be performed for multiple files at once in the Channel Editor.
When using the HEAD Recorder (version 7.0 or later) you can save the sensor definition for digital pulse channels during recording, so this step becomes unnecessary for files with digital revolution speed information.
For detailed information on editing sensor information and creating a new trigger channel in the Channel Editor, also refer to the online help of the HEAD Recorder and in the Help System of ArtemiS SUITE.
After creating and saving the sensor information, return to the Decoder Project. In the next step, configure the decoder according to your needs.
The following settings (see figure 4) are available. Note that settings marked with ⁺ are only available for the trigger decoder.

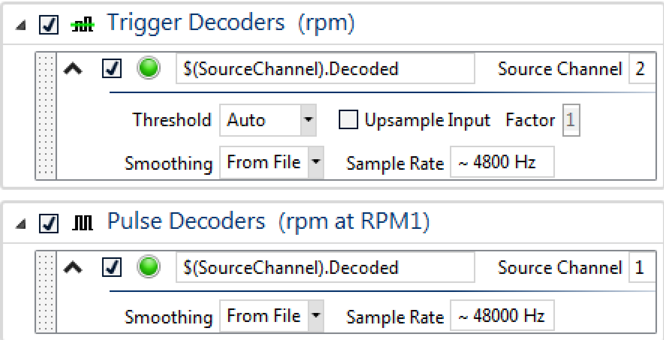


Figure 4: Trigger decoder (top) and pulse decoder (bottom) in the Decoder Project

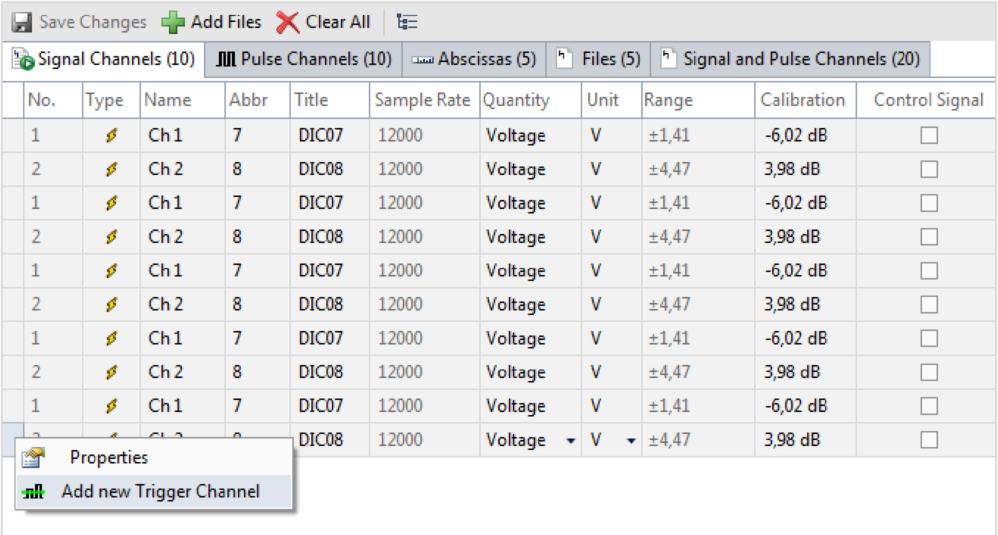
- ***Source Channel***: Here you can enter the trigger channel created in the Channel Editor. You can enter either the channel name or the channel number (the wildcard character * is supported).
- ***Threshold⁺***: Here you can specify the threshold value for pulse detection. Three settings are available: ***Auto***, ***Relative***, and ***Manual***. A detailed description of the available options can be found in the Help System of ArtemiS SUITE.
- ***Upsample Input, Factor⁺***: If this option is enabled, you can enter a factor by which the existing analog signal is to be upsampled prior to threshold detection. For example, in cases where the sampling rate is low compared to the measured revolution speed, upsampling reduces the number of artifacts and thus leads to more reliable decoding due to the more precise interpolation of the signal curve (see also section “Application examples”).
- ***Smoothing***: Here you can choose whether and how strongly the data are to be interpolated (averaged) when sampled.
- ***Sample Rate***: Here you can enter the desired sampling rate for the decoded channel. Depending on the source file, the actual sampling rate can differ slightly, as it is adapted for optimal saving in the HEAD Data Format. The actual rate is displayed in the legend of the preview.

Once the decoder is configured and the preview shows the correct revolution speed curve, the new file(s) can be created with a click on the abacus icon and inserted into a Pool Project for further analysis. A very convenient way to do this is via the ***Recent Results*** list of the HEAD Navigator. The most recently calculated results can be found at the beginning of this list and can simply be dragged and dropped into a Pool Project.

[3] If you want to preserve your original files, you should make copies of them in advance.

Application examples

For the first application example, the revolution speed was recorded as an analog channel using a magnetic sensor on a toothed wheel with 132 teeth. First, the files are opened in the Channel Editor, and a trigger channel is created. If you have recorded several files, you can select them all and jointly insert them into the Channel Editor, where you can also create the trigger channel for multiple files at once (see figure 5).



No.	Type	Name	Abbr	Title	Sample Rate	Quantity	Unit	Range	Calibration	Control Signal
1		Ch 1	7	DIC07	12000	Voltage	V	±1,41	-6,02 dB	☐
2		Ch 2	8	DIC08	12000	Voltage	V	±4,47	3,98 dB	☐
1		Ch 1	7	DIC07	12000	Voltage	V	±1,41	-6,02 dB	☐
2		Ch 2	8	DIC08	12000	Voltage	V	±4,47	3,98 dB	☐
1		Ch 1	7	DIC07	12000	Voltage	V	±1,41	-6,02 dB	☐
2		Ch 2	8	DIC08	12000	Voltage	V	±4,47	3,98 dB	☐
1		Ch 1	7	DIC07	12000	Voltage	V	±1,41	-6,02 dB	☐
2		Ch 2	8	DIC08	12000	Voltage	V	±4,47	3,98 dB	☐
1		Ch 1	7	DIC07	12000	Voltage	V	±1,41	-6,02 dB	☐
				DIC08	12000	Voltage	V	±4,47	3,98 dB	☐

Figure 5: Selecting multiple files in the Channel Editor

Clicking on the command ***Add new Trigger Channel*** opens a window where you can edit the channel name, the quantity, and the measurement unit (e.g., revolution speed in rpm or angle in °). In our example, the default settings (***Speed of Rotation*** and ***rpm***) are left unchanged. Afterwards, click on ***Edit Pulse Sensor Geometry*** to specify the sensor information.
In the ***Pulse Sensor Geometry Editor*** window, first enter the number of teeth and specify whether their distance is constant (equidistant). Then click on ***Create Sensor*** (see figure 6). Next, specify any gaps between the teeth or the distribution pattern if the teeth are not equidistant.

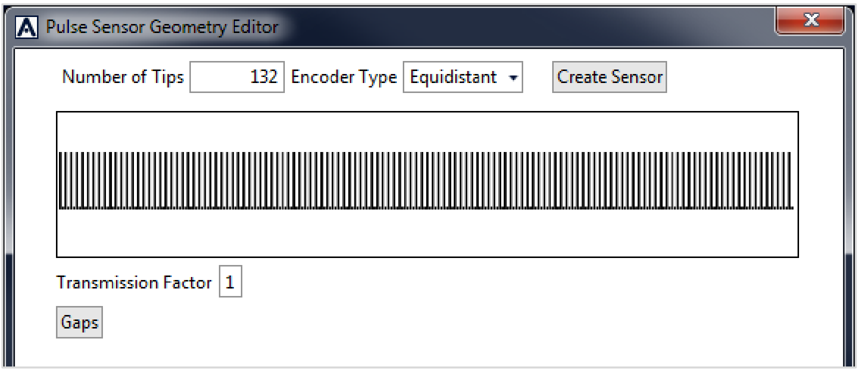


Figure 6: Pulse Sensor Geometry Editor

Confirm each of your entries with the ***OK*** button; then click on ***Save Changes*** in the Channel Editor to save the sensor information for all selected channels.
Now insert the files into a Decoder Project with a trigger decoder. When configuring the trigger decoder, be sure of the correct selection of the input channel and a sufficiently high sampling rate.
Then click on the abacus icon to start the calculation.

Now drag and drop the newly created files from the ***Recent Results*** list into a Pool Project, and activate the newly decoded revolution speed channel for a calculation (see figure 7).

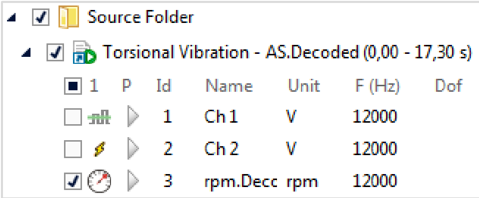


Figure 7: Time domain signal in the Source Pool with activated newly decoded revolution speed channel

Figure 8 shows an example representation of the revolution speed curve without an analysis function applied.

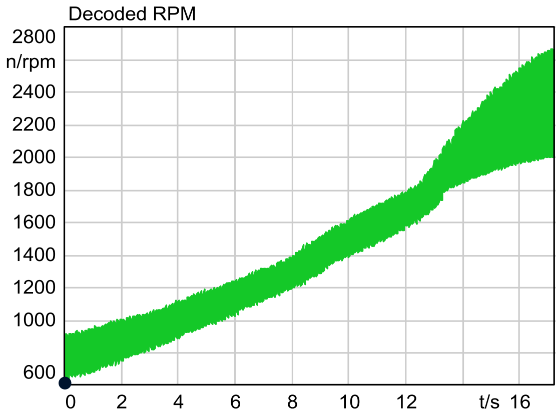


Figure 8: Revolution speed curve versus time

In many cases, only the alternating component of the revolution speed is of interest. With a simple high-pass filter (e.g., at 5 Hz), the constant component can be removed. Figure 9 shows the revolution speed curve of figure 8 without the constant component.

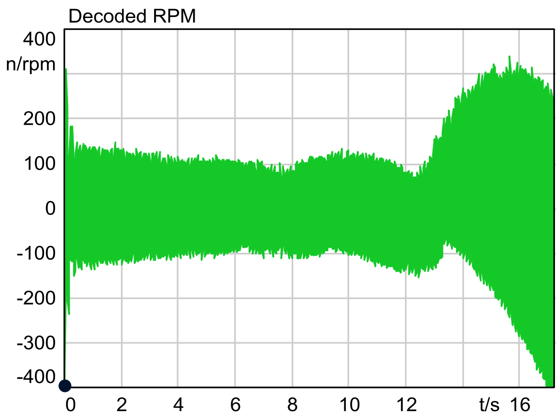


Figure 9: Revolution speed curve versus time without constant component

Of course, the time domain signal shown here can also be subjected to analysis. Frequently used analysis functions in this context are ***FFT vs. Time*** or ***RPM*** and ***Order vs. RPM***.
In order to perform an analysis versus revolution speed, it can be useful to record the revolution speed not only with a high sampling rate, but also to record a simpler (smoothed) revolution speed signal in parallel, which can then be used as the reference quantity for the analysis against revolution speed.

Figure 10 shows the result of the ***FFT vs. RPM*** analysis of the revolution speed curve shown in figure 9. The analysis shows the temporal variation of the revolution speed, i.e., the torsional vibration. In our example, artifacts are visible in the high-frequency range, which are caused by inaccuracies in the interpolation of zero-crossings.

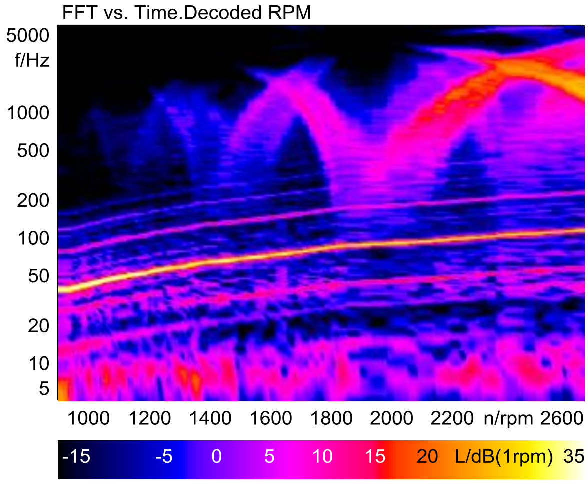


Figure 10: ***FFT vs. RPM*** of the revolution speed curve shown in figure 9

The following application example shows how such artifacts can be reduced.
Figure 11 shows an ***FFT vs. Time*** analysis of another revolution speed curve. For this example, the revolution speed was recorded to an analog channel with a sampling rate of 48 kHz. The toothed wheel had 89 equidistant teeth. In the Decoder Project, no upsampling was used for the calculation of the decoded pulse channel.

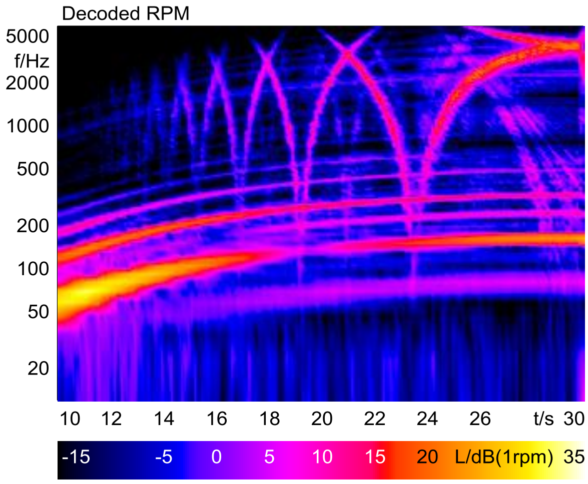


Figure 11: ***FFT vs. Time*** analysis of a revolution speed curve

Figure 12 shows another FFT analysis of the same signal, but this time the signal was decoded with 10-times upsampling. It is obvious that the upsampling in the decoding process leads to a significant reduction of artifacts in the high-frequency range.

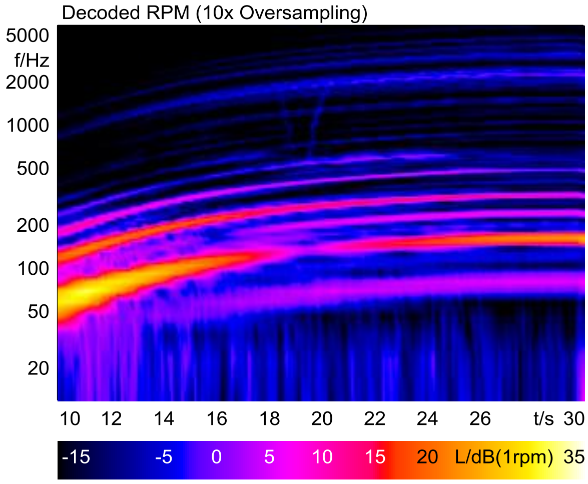


Figure 12: ***FFT vs. Time*** of the same revolution speed curve as in figure 11 after upsampling

For the recording used in this example, the revolution speed was additionally recorded to a digital pulse channel. Figure 13 shows the ***FFT vs. Time*** analysis of the decoded digital pulse channel.

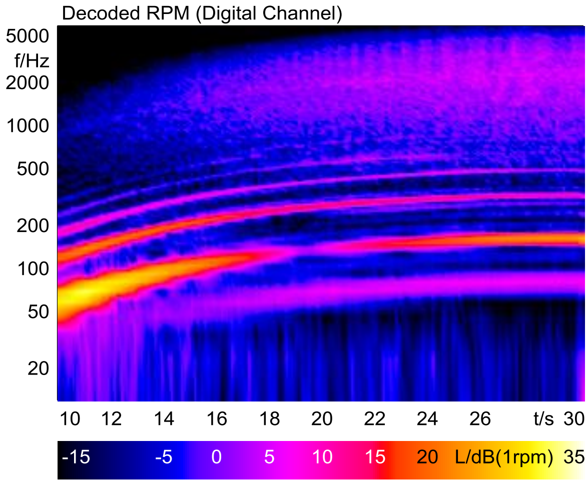


Figure 13: ***FFT vs. Time*** analysis of a revolution speed curve recorded as a digital pulse channel

The comparison to figure 11 shows that the evaluation of such a signal does not lead to artifacts as occur in the evaluation of an analog revolution speed channel sampled with a low sampling rate. Instead, the signal becomes noisy in the high-frequency range. This is caused by the lack of interpolation to find the exact zero-crossing points. In comparison, the momentary revolution speed of an analog channel can be determined very precisely using the zero-crossing interpolation described on page 2. A revolution speed curve recorded as a pulse channel does not allow for interpolation, so the momentary revolution speed is determined with a comparatively low accuracy. For a qualitative analysis, however, the decoded revolution speed is still sufficient with this method. That way, a torsional vibration analysis can also be performed in cases where the revolution speed cannot be recorded to a separate analog channel.

Notes

For the applications described in this Application Note, you need the following ArtemiS SUITE modules: **ASM 00** Basic Framework (code 5000), **ASM 01** Basic Analysis Module (code 5001), **ASM 04** Data Acquisition Module (HEAD Recorder for recording the signals, code 5004), and **ASM 24** Data Preparation Module (code 5024).