Using a frequency offset in order calculations

ArtemiS SUITE[1] provides a function allowing a frequency offset for order analysis and order cursors. This function was developed for hybrid and electric vehicle programs, for analyzing noise from three-phase AC motors. This type of motor produces an order spectrum containing not only the usual rpm-proportional orders, but also additional frequencies. These include the switching frequency of the inverter(s) and the sidebands around this frequency, resulting in an unusual order spectrum requiring the use of order-cursor, order-analysis or order-tracking filter frequency offsets.

Introduction

Figure 1 shows the FFT spectrogram of noise from an electric motor plotted against the RPM of the motor. The spectrogram shows motor orders increasing with RPM in the range of 400 to 5000 Hz and the constant switching frequency of the inverter (at 7300 Hz). Furthermore, several side bands around the switching frequency are visible, which increase or decrease with increasing rpm values – these are orders related to RPM, but not quantifiable with conventional order cursors or order definitions.

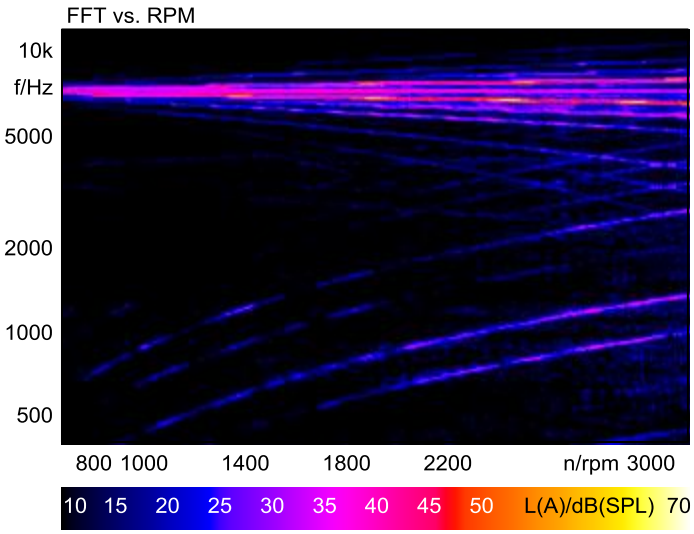


Figure 1: FFT spectrogram of noise from an electric motor

The frequencies of these side bands are determined by the revolving-field frequency of the three-phase motor[2]. From a communications engineering point of view, they form a modulation spectrum with the switching frequency of the inverter as the carrier frequency. Since the revolving-field frequency changes proportionally to the motor RPM, increasing RPM values result in the fan-shaped pattern of increasing and decreasing frequencies as the sidebands diverge both above and below the inverter switching frequency.

[1] The descriptions in this Application Note refer to ArtemiS SUITE 9.0. The general procedures also apply to other versions. However, the scope of functionality and the user interface may differ.
[2] The frequency of the revolving field is the product of the motor RPM multiplied by the number of poles used in the motor.

Before performing offset-order analysis (see chapter “Frequency offset in an order analysis”), it is recommended to explore a spectrum vs. RPM with an offset data cursor (see next chapter), to determine not only if an offset is necessary but also (if it is), what offset-orders are present (negative and positive). In this way, you can make an informed setting of the order range in the properties of the order analysis to include all necessary orders.

Data Cursor with frequency offset

When using the Data Cursor in ArtemiS SUITE, a tooltip is shown for 3D analyses in the diagram. As with the analysis ***FFT vs. RPM***, this tooltip shows the level as well as the order number for the current cursor position. Moreover, another reference line is shown, on which the ratio of the two abscissas remains constant. This line corresponds with the order curve. Based on the cursor position, the order number is normally determined as the quotient of frequency and revolutions (per second). For example, a cursor positioned at 3000 RPM, i.e., 50 revolutions per second, and at a frequency of 2600 Hz results in the 52nd order.

Reading the orders in relation to the switching frequencies of the inverter even requires a frequency offset for the Data Cursor. If the Data Cursor is active in a diagram, a click on F2 opens an input window in which you insert numerically the desired frequency offset of the order line on the second abscissa (Y-axis). Afterwards, press the Enter key to set the frequency offset. The value of the frequency offset is indicated as an additional information in the tool tip. The frequency offset can be deleted by inserting ***0*** into the input window.

As an example figure 2 shows an ***FFT vs. Time*** with a Data Cursor without frequency offset in the left diagram. The right diagram shows the same analysis but with an activated frequency offset of 7300 Hz.

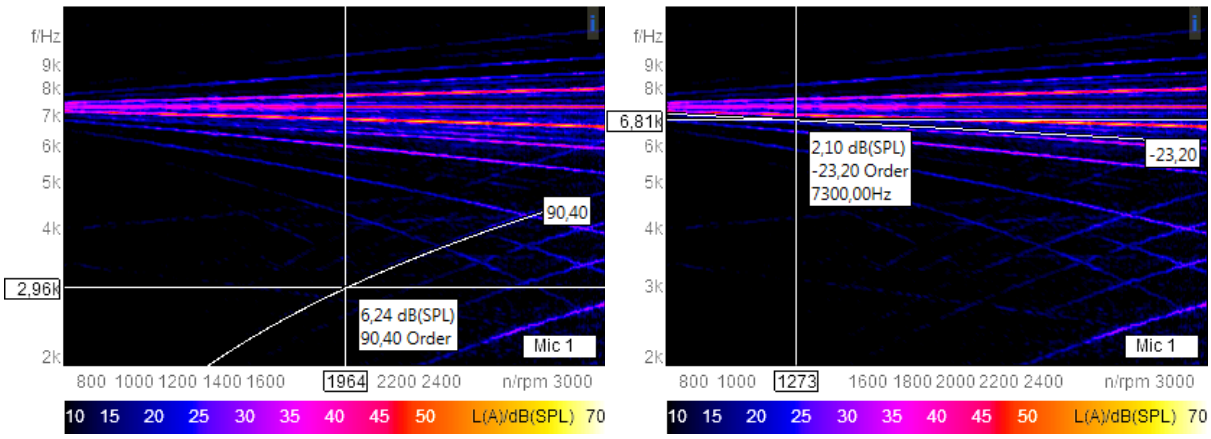


Figure 2: Data Cursor without (left diagram) and with offset (right diagram)

Frequency offset in an order analysis

If a sound containing rpm-dependent orders is analyzed with an order analysis, the curved lines shown in the FFT spectrogram become straight lines defined on an order ordinate. By means of order analysis, an acoustical engineer can easily determine which noise components are caused by the motor revolution and which of these orders are particularly dominant in the spectrum.
Figure 3 shows the order spectrum of the same signal as in figure 1. The lower part of the diagram shows the constant motor orders, but a group of curved lines also appears.

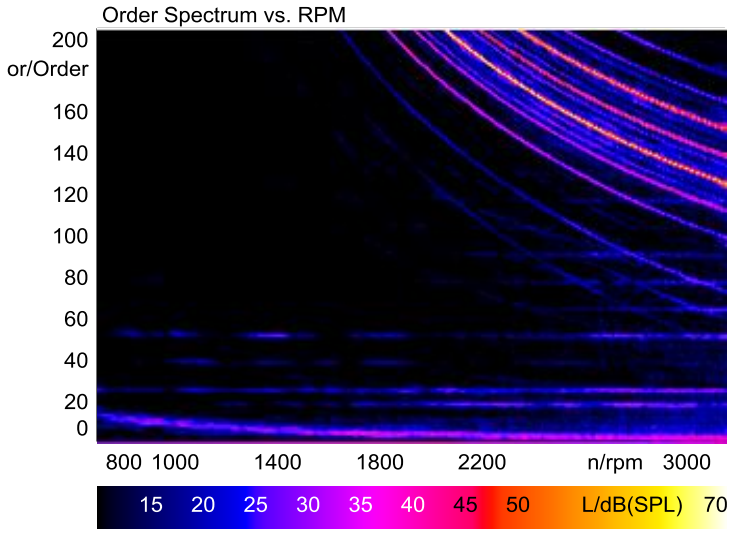
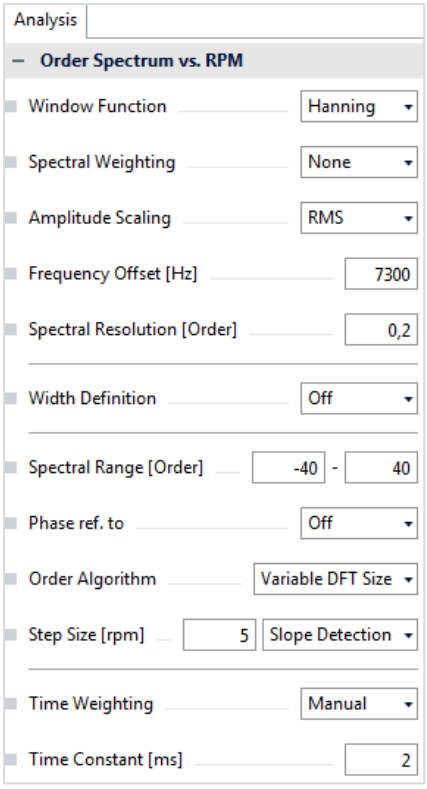


Figure 3: ***Order Spectrum vs. RPM*** of the signal analyzed in figure 1



The curved lines are the fan-shaped orders (sidebands surrounding the switching frequency of the inverter). They cannot be analyzed meaningfully with a standard order analysis, nor will they align with a standard Data Cursor.
However, by changing a setting in the Properties window of the order analysis, it is possible to determine meaningful results for these curves as well. To do so, the switching frequency of the inverter must be entered in the field labeled ***Frequency Offset***. Figure 4 shows the Properties window of the analysis with the correct value entered for our example (frequency offset of 7300 Hz).
Besides the entry of the ***Frequency Offset***, the ***Spectral Range*** has been adapted as well.
If the settings mentioned in figure 4 are used, the result shown in figure 5 is achieved.
You can find a detailed description of the additional settings and corresponding application examples in the application note “Order analysis in ArtemiS SUITE”.

Figure 4: Properties window of the analysis ***Order Spectrum vs. RPM***

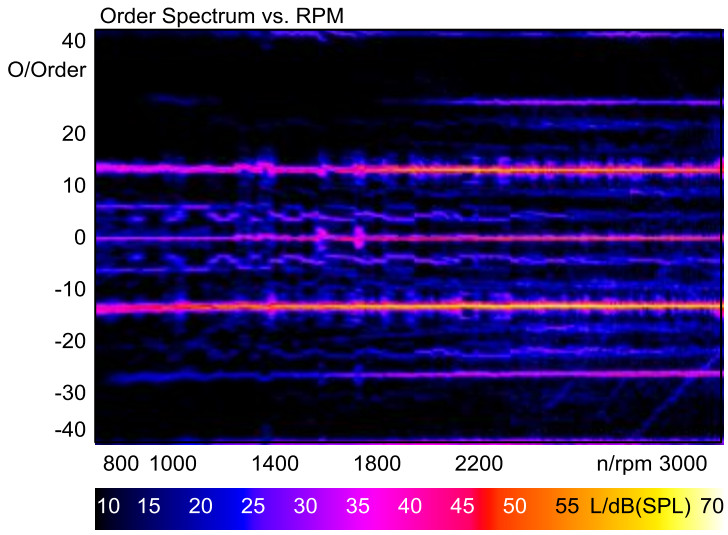


Figure 5: ***Order spectrum vs. RPM*** result with frequency offset

By using the frequency offset in calculating the order spectrum, the curves surrounding the switching frequency of 7300 Hz can be converted to the desired representation and interpreted as orders.

Frequency offset for order filters

The offset function is also available for order-tracking filters. Without a frequency offset, tracking filters can only act on conventional orders, as illustrated in figure 6, whose left diagram shows the unfiltered signal. In the right diagram, the 26th engine order was removed.

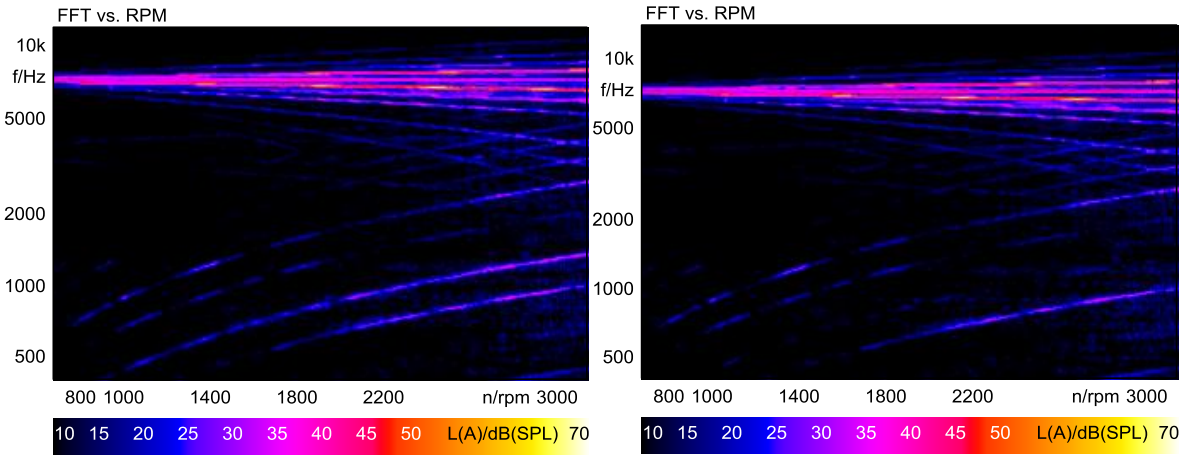


Figure 6: ***FFT vs. RPM***, unfiltered (left) and filtered with a tracking filter for the 26th engine order (right)

On the other hand, to filter frequencies centered on the switching frequency of the inverter, the offset function is applied to the order-tracking filter. This allows orders related to switching frequency of the inverter to be removed from the signal, or modified. In figure 7, the 13th and negative 13th orders relative to the switching frequency of 7300 Hz were filtered out (right diagram). The left diagram shows the unfiltered signal for comparison.

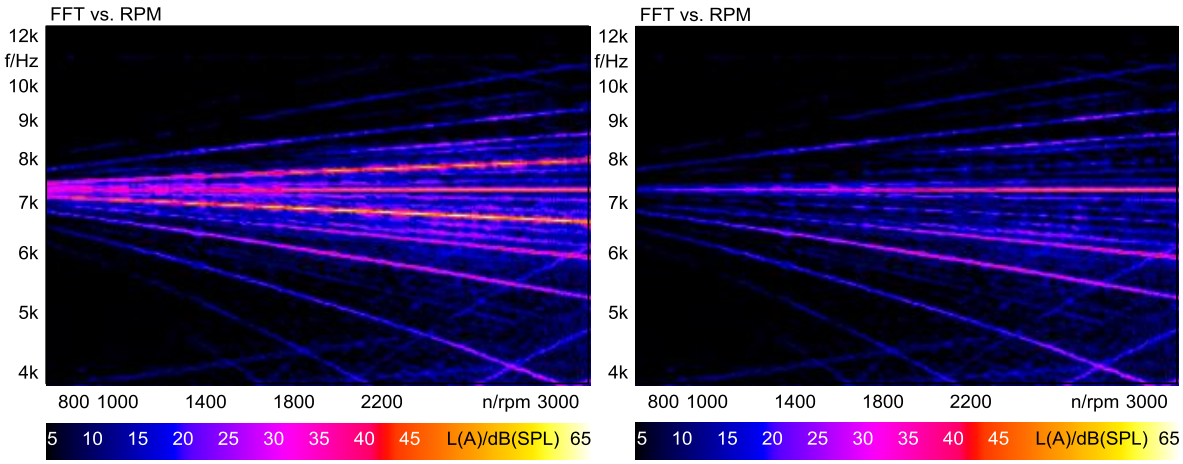


Figure 7: ***FFT vs. RPM***, unfiltered (left) and filtered with a tracking filter with frequency offset (right)

The option to set and activate an offset for a tracking filter is available in the Properties window of IIR filters in the Filter Pool (see figure 8).

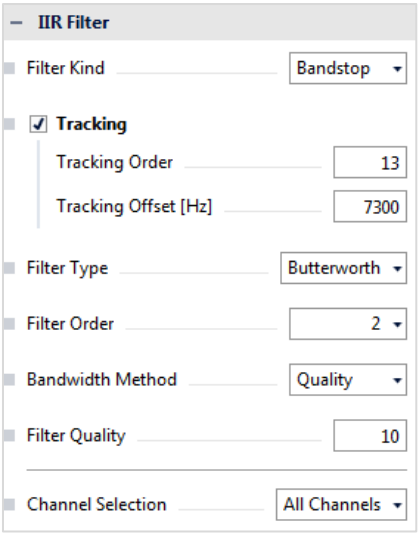


Figure 8: Properties window of an IIR Filter

After activating the ***Tracking*** function you can enter the desired ***Tracking Order*** and ***Tracking Offset*** into the corresponding input fields.
Furthermore, the ***Filter Quality*** must be adjusted in certain cases. The filter quality is the quotient of the center frequency and the bandwidth of the filter. Due to the frequency offset, an offset-order center frequency can be very high in some cases. To obtain an appropriate filter bandwidth, a relatively high filter quality is required. You can avoid this problem by switching the ***Bandwidth method*** from ***Quality*** to ***Bandwidth [Order]***. Afterwards you can specify the filter bandwidth in terms of the desired order width rather than by filter quality.

Notes

For calculating the analyses presented in this Application Note by means of a Pool Project, you need the following ArtemiS SUITE modules: **ASM 00** ArtemiS SUITE Basic Framework (code 5000) and **ASM 01** ArtemiS SUITE Basic Analysis Module (code 5001).
If you want to calculate the analyses and use a tracking filter by means of an Automation Project or a Standardized Test Project, you may need other modules. Your HEAD acoustics representative will gladly provide you with further information.

Do you have any questions or remarks? Please write to:
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We look forward to receiving your response!