# Gear Tooth Analysis Using Cyclic Time Averaging and Machine Analyst / HMI

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## Introduction

This article describes a new vibration analysis technique named Cyclic Time Averaging (CTA) that is available with SKF's Machine Analyst / HMI (Human Machine Interface) software application. The Cyclic Time Averaging technique is similar to the well-established Synchronous Time Averaging method, with the major difference being that with Cyclic Time Averaging, an external hardware trigger is not required.

## What is Synchronous Time Averaging?

Synchronous Time Averaging is a process in which you use an external 1X r/min trigger to time synchronize and average data collected from the machine. The sampled data is continuously synchronized to the 1X trigger, resulting in the time domain data being phase coherent to the machine running speed. When the time data is sequentially averaged, only integer ordered data amplitudes are enhanced; all non-synchronous peaks tend to a zero average. This technique enhances desired signals while minimizing unwanted vibration signals from, for example, nearby machines. This method is also useful for applications such as balancing, since it maintains an accurate and stable phase measurement.

## What is Cyclic Time Averaging?

Cyclic Time Averaging is a post processing technique where a data ensemble containing a number of consecutive machine cycles are re-sampled, summed and then averaged. The re-sampling is based on a sync pulse (trigger) that does not physically exist. Instead of an external trigger, Cyclic Time Averaging uses a user-defined trigger.

Like Synchronous Time Averaging, Cyclic Time Averaging is a useful tool in situations where data averaging that is based on certain events is required to assess vibration from a specific source, or to eliminate the influence of an unwanted vibration source. Unlike Synchronous Time Averaging, in the Cyclic Time Averaging process, absolute shaft phase data is not coherent with the machine cycle. Cyclic Time Averaging may be used instead of Synchronous Time Averaging whenever the required trigger is not readily available.

## Example: using Cyclic Time Averaging for gear tooth analysis

One of the best cases for using Cyclic Time Averaging is when an external trigger is not possible, or practical, such as when monitoring the inner shafts of a gearbox. For example, a vibration analyst decides to take a close look at the waveform from each gear tooth of the gear engaging the high-speed shaft pinion, as shown in **fig. 1**. The goal is to find out if there are damaged gear teeth on the gear, without having to stop the machine and open it up for inspection.

Averaging based on a shaft trigger from the intermediate shaft would be required to enhance signatures from potentially damaged gear teeth. The problem is that there is no trigger on the intermediate shaft, and it is impossible to install one since the shaft is inaccessible. Cyclic Time Averaging is the only way to look closely at the waveform generated by each tooth from that gear.

The Cyclic Time Averaging algorithm is implemented in the Machine Analyst / HMI software package and so provides an easy tool for Machine Analyst users to perform Cyclic Time Averaging analysis on data stored in their database. To get a useful Cyclic Time Averaging analysis result, it is important to collect the data with an appropriate measurement setup. The rule of thumb is to ensure that the sample rate is high enough to provide good resolution of the event, but not so high that there is not enough data to perform the averaging.

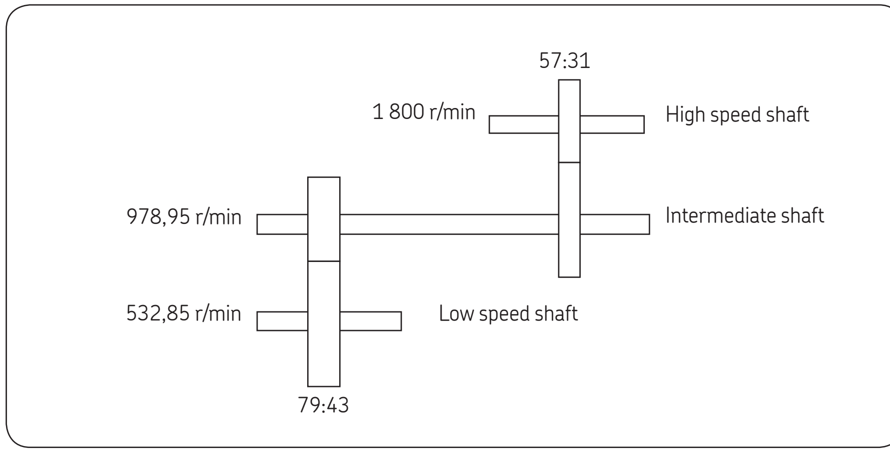


*Figure 1. A gearbox with suspected intermediate shaft gear tooth damage.*

For our example of a damaged gear tooth, the event is defined as the duration from the initial contact of two gear teeth until the end of the contact. It is decided that 50 samples per gear tooth engagement is preferred. The sample rate can then be estimated as following:

- Given:
  - Samples/tooth = 50
  - Number of teeth = 57
  - Shaft speed = 978,95 r/min

The sample rate is determined as follows:

- Sample rate = 50 (samples/tooth) × 57 (teeth) × 978,95 / 60 (Hz) = 46,5 kHz

Thus, the corresponding analysis bandwidth $f_{max}$ = 46,5 kHz / 2,56 = 18,16 kHz (~20 kHz). The choice for number of lines is 6 400, providing the maximum amount of data for averaging when using an SKF Multilog LMU (Local Monitoring Unit) data acquisition device. In the new SKF Multilog CMU (Condition Monitoring Unit), the maximum number of lines is 12 800, giving twice the resolution.

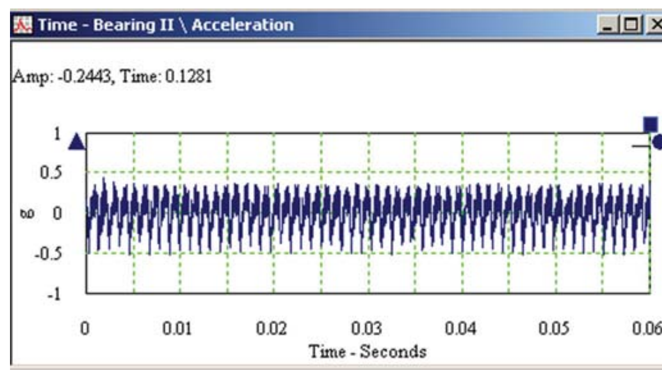


*Figure 2. Time domain waveform during one shaft revolution.*

To demonstrate the use of the Cyclic Time Averaging algorithm to enhance the signature from the damaged gear tooth, a measurement POINT is set up in Machine Analyst / HMI to process the gearbox time domain data stored in the Machine Analyst database. The time domain waveform for one shaft revolution is plotted in **fig. 2**. Notice there are 57 cyclic events shown in the plots, representing 57 gear tooth engagements.

The waveform provides no clear evidence of any bad gear tooth.

In Machine Analyst / HMI, the same waveform is presented in **fig. 3**. Machine Analyst / HMI provides three plots, which are:

- The waveform for the entire data block is plotted in the upper left corner, with the highlighted portion showing the waveform for the first revolution. The user can progress through the subsequent revolutions using the slide bar in the tool bar area.
- The data block's spectrum is plotted in the lower left corner.
- A profile plot of a single revolution's time waveform (from the highlighted portion of the upper left waveform plot) displays on the right side.

After clicking the toolbar's ⌧ button to initiate the Cyclic Time Averaging process, Machine Analyst / HMI performs the calculations and displays the result as shown in **fig. 4**. The three provided plots are:

- The cyclic time averaged waveform is plotted in the upper left corner.
- The spectrum for the averaged data is plotted in the lower left corner.
- The profile plot of the cyclic time averaged waveform is displayed on the right side.

In the profile plot, it is clear that the damaged gear tooth generates a significant amount of high frequency vibration during initial contact with the mating tooth. Remarkably, only five-averages are needed to bring out this damaged gear tooth signature.

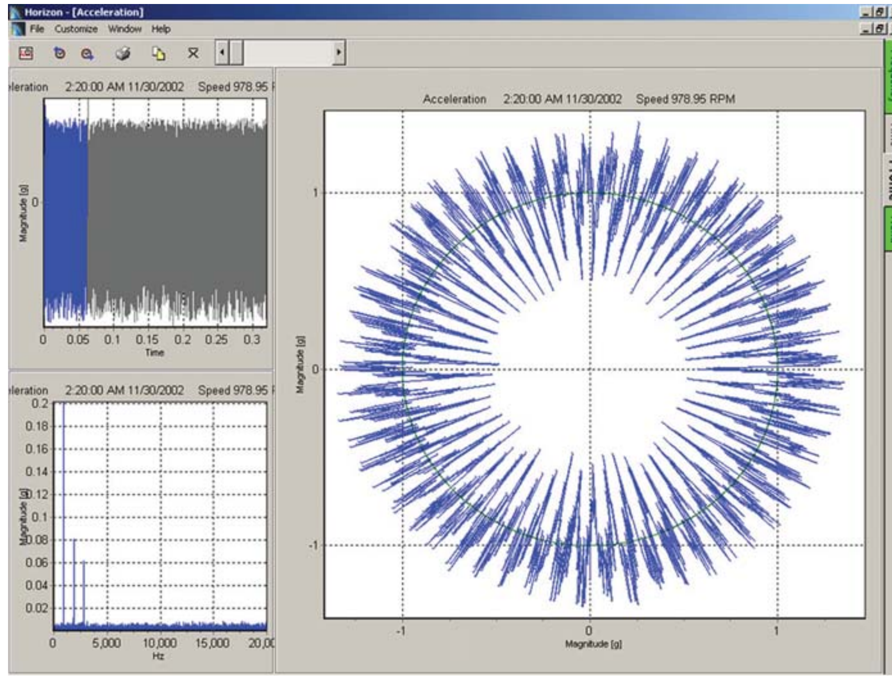


*Figure 3. SKF Machine Analyst / HMI's presentation of time domain waveform and spectrum before Cyclic Time Averaging.*

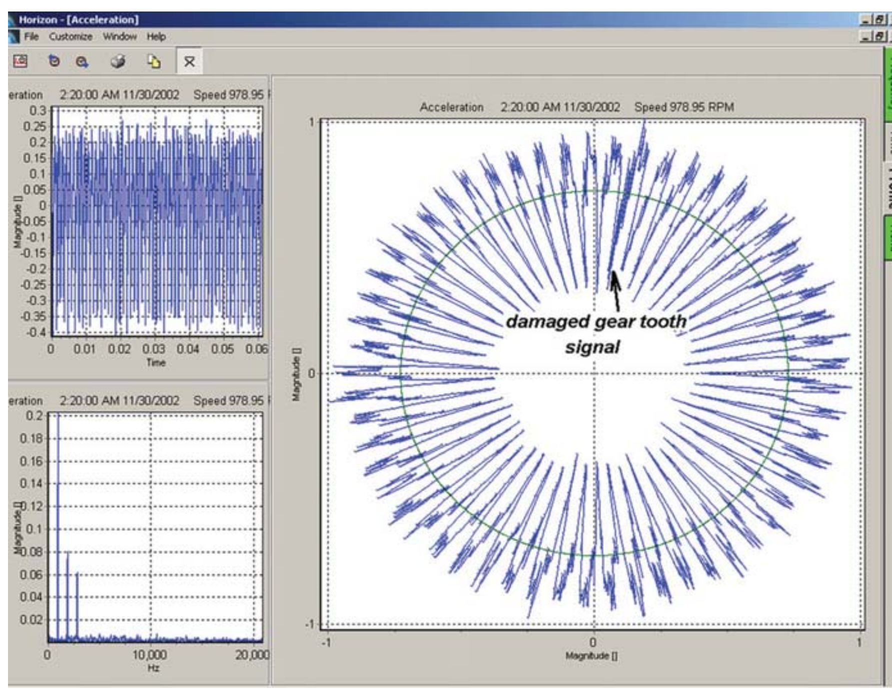


*Figure 4. Machine Analyst / HMI's presentation of time domain waveform and spectrum after Cyclic Time Averaging.*

In a similar example, **fig. 5** shows the resulting Cyclic Time Averaging profile plot for a gear with three defective teeth. These defects are clearly indicated by the three largest spikes in the profile plot.

## Conclusion

Cyclic Time Averaging is a power tool for rotating machinery vibration diagnosis and condition monitoring, particularly when an external synchronous trigger for the averaging process is not available. For customers using SKF Machine Analyst, the Machine Analyst / HMI software provides a very easy-to-use interface to perform Cyclic Time Averaging calculations and display their results.

It should be noted that while Synchronous Time Averaging requires a variable sample rate to track an external trigger, Machine Analyst requires a relatively stable rotational speed, with recommended speed deviations of no greater than 1%.

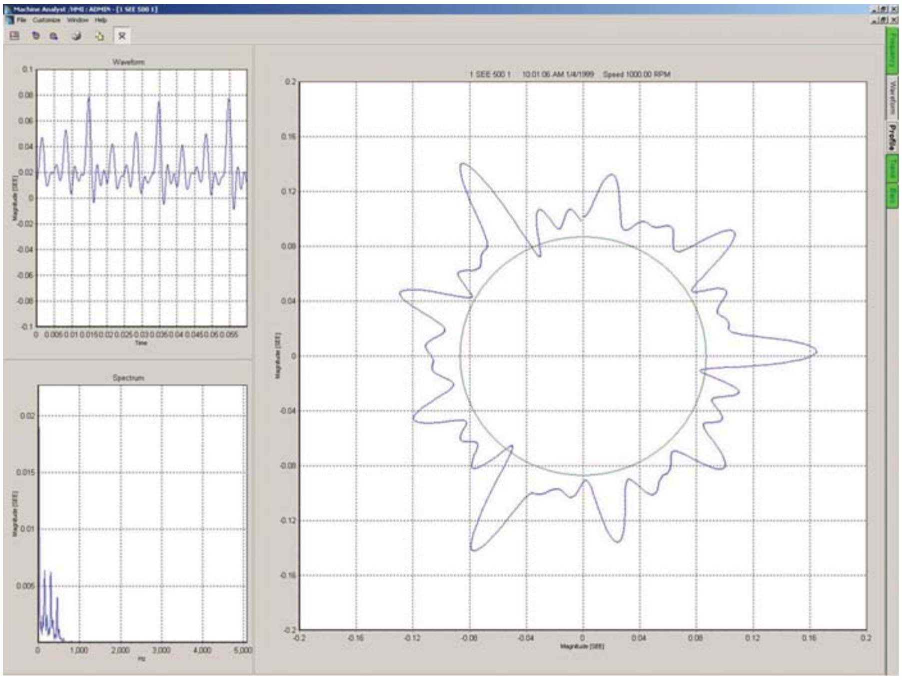


***Figure 5. Cyclic Time Averaging display showing three defective teeth on a gear.***

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