Synchronous Time Averaging

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Requirements

This article assumes the reader has good knowledge of vibration monitoring and some basic understanding of averaging.

Abstract

Vibration analysis involves interpreting vibration signals which may emanate from multiple sources. Due to the fact that virtually all rotating machines have several bearings, a shaft, a gearbox or some gearing arrangement (such as, chains, belts, etc.), all supported and linked by the frame on which they are mounted, determining the source(s) of the main vibration signal can be a difficult and complex task. Efforts may be further complicated when the dynamic forces causing the vibration excite other machine parts to vibrate empathically. Therefore, to aid in identifying the vibration source(s), different measurement techniques are used to form a set of discriminating results. Common techniques are; acceleration vs. velocity, filters, and acceleration enveloping. Synchronous Time Averaging is another technique that can be used to help identify the vibration source.

Averaging

In a hypothetical environment, a rotating machine with a single vibration source and no process changes will always display the exact same overall vibration value. If we add vibration "noise" to this environment, the overall values will reflect the true value plus some random offset that is added or subtracted from the true value due to the noise. Taking a series of overall values shows a trend that meanders around the true value. It is possible to gain a more accurate value by using a simple property of noise; that noise generally consists of values that are distributed across the spectrum evenly. For instance, in one measurement the true vibration value may be a bit higher, in another it may be a bit lower. Therefore, if one takes a series of these overall values and performs a simple average calculation, the result is a more accurate value that is closer to the true value.

Synchronous Time Averaging (STA)

The averaging process described above operates on consecutively acquired overall values. However, for many vibration diagnostic cases a time waveform and its resulting spectrum are required. Waveforms can also be averaged, but the technique requires that data acquisition begins at a very precisely defined moment. To understand this, it is important to realize that vibration signals are recordings of cyclical processes in the rotating machine under observation.

For example, a gearbox with a broken tooth has a vibration signal that appears repetitive with the repetition frequency being that of the broken tooth. Every gear revolution, the broken tooth is engaged in the same way and therefore produces a vibration signal that is very similar to previous revolutions. It is a cycle that repeats itself over and over again. However, the signal that is recorded by the sensor also includes other vibration sources that have a different period from the broken tooth. These are said to be out of synchronization with the broken tooth signal. This means that each

Table 1. Averaging 10 values with noise shows a marked improvement in accuracy.

Time value	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Noise	–0.1910	–0.0920	–0.0190	0.3834	0.2611	0.3720	–0.4840	0.1839	–0.3980	0.1060
Measured	2.2080	2.3070	2.3800	2.7834	2.6611	2.7720	1.9150	2.5839	2.0010	2.5060
Averaged	2.4120									

time the gear engages the broken tooth, vibration signals from other sources are at a different point in their respective cycle and therefore their vibration signals vary, as seen by the sensor. One could regard the other vibration sources as “noise” added to the broken tooth vibration signal, noise that sometimes adds, sometimes subtracts from the “true” value.

Recording a time waveform with the aim to use it for averaging requires that:

- the sampling process always starts at the same position in the repetitive cycle, and
- a fixed number of samples are used.

The first requirement ensures that a succession of time waveforms can indeed be averaged, as the position of defect signals always fall in the same area of the time waveform array. If instead, the sampling process is permitted to start at any time, the signal impulses created by the defect generally will not line up and therefore eventually average each other out.

It is perhaps easiest to consider the signals we are averaging as data on a circular plane. After all, the processes that generate these signals are cyclic and therefore reoccur. The gearbox example above creates a signal that could be depicted on a circle with a period equal to the shaft speed.

To ensure that sampling always starts at the same point in the process cycle, the data acquisition device requires a trigger signal that indicates to the data acquisition device that sampling must start at the time the trigger signal goes from inactive to active. Trigger signals may be created by, for example; an eddy current probe aimed at the keyway in the shaft, or a laser-trigger for the felt in a paper machine. They may also be created by a control system output or other dedicated electronics for the machine under observation. It is important to realize that the trigger signal must occur only once per cyclic event. Therefore, a device with a speed wheel – often used to improve RPM reading accuracy – cannot be used for STA measurements.

However, vibration sensor signals can be used with more than a single trigger signal. Using a paper machine press section as an example, the machine may be equipped with both a press roll trigger and a felt trigger. Each is connected to the data acquisition device in addition to the accelerometer sensors mounted on the press roll bearings. This allows for an STA measurement synchronous to the felt, and a second STA measurement synchronous to the press roll rotating frequency.

Note that Synchronous Time Averaging must be performed by the data acquisition device (such as, it cannot be computed as a post process by the software application running on the PC).

Spectral Averaging

The same principals as described above for overall averaging works for spectral averaging (this is not STA). The spectral averaging algorithm works by accumulating the sum of a series of spectra and finally dividing this result by the number of spectra accumulated. One should notice that spectra are void of phase information and therefore the averaging process is much less discriminating than the STA process as discussed above. Spectral averaging does not require a trigger.

What noise improvement levels can be expected when using Synchronous Time Averaging?

When setting up a measurement for STA, you need to determine a practical setting for the number of averages. After all, increasing the number of averages increases the total measurement time. For example, a measurement with FMax set to 100 Hz and number of lines set to 800 takes 8 seconds to acquire. Therefore 8 averages is already more than 1 minute to acquire this measurement. For STA readings taken with a portable device, one must also carefully set up the system to ensure stable vibration signals. Therefore, use a sensor attached to a magnet or otherwise rigidly mount the sensor. Also, ensure the attached cable is not heavy and not significantly vibrating. If the sensor is not rigidly mounted, the introduction of the hand movements will negatively offset the accuracy gains achieved from STA.

The higher number of averages, the better the noise improvement and the more non-synchronous signal is removed from the resulting time waveform. But how much improvement can be expected with each average? This question has actually a fairly simple answer; every doubling of the number of averages has a noise improvement level of a factor 2. A factor of 2 seems the smallest meaningful/detectable improvement. Often times, signal to noise ratios are expressed in decibel, a factor of 2 is computed to be 20 * log (2) = 6 dB. So if a measurement is set for 16 averages and an improvement in the noise reduction is required, setting 32 averages facilitates an improvement of 6 dB.

The following figure shows the improvement of the signal to noise ratio whereby a single sine wave signal with noise is acquired and averaged with 4, 8, 16, or 32 averages. The reduction in noise with both time waveform and spectrum plots is clearly visible. The number inside the spectrum plot is the measured signal to noise ratio for that measurement.

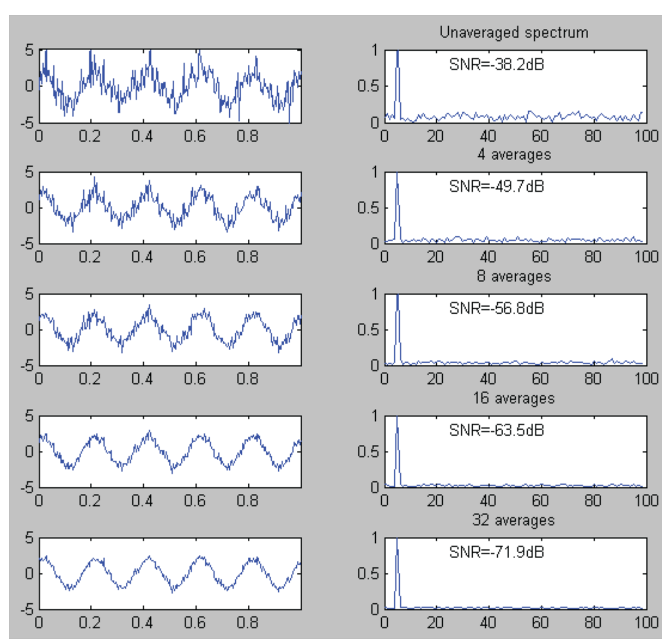


Figure 1. Signal to Noise ratio improvement with increasing number of averages.

However, don't expect a steady improvement of 6 dB with every doubling of the number of averages. There are several processes that counteract the averaging process, and these increase their impact with an increasing number of averages. Specifically, the machine speed or other machine processes might not be stable enough to support a high number of averages. Secondly, the trigger mechanism or its setup may have a limitation that causes trigger jitter, which in turn causes the acquired signal to be slightly out of sync with acquired measurement.

The pitfalls of averaging

Although averaging, and in particular synchronous time averaging, can provide meaningful data, one must always take care when interpreting the end result. An STA measurement should be regarded in addition to standard, non-averaged signals to obtain an overall view of the situation at hand. The paragraphs below detail a few of the possible misinterpretations common to STA users.

Mechanical resonance influence

A mechanical resonance is a phenomenon whereby signals within a certain spectral frequency range are amplified. Most often, this is a relatively broad area with an amplification factor that peaks in the middle and tapers off to the sides. Signals created by impacts or sudden changes create a series of vibration frequencies – often referred to as a harmonic series. This harmonic series may contain signal content in the resonance area. This means that the frequency content from the impact source that falls in the resonance area is amplified by this resonance. Applying an STA measurement synchronous to the defect signal, does NOT remove the influence of the resonance. Quite the contrary, it will show the resonance even more clearly. Depending on the particular situation at hand, the resonance characteristics might change due to mechanical changes or maintenance done to the machine. For impulsive fault signals, this implies that their perceived energy content changes. If the STA measurement is the only measurement applied to the fault (such as, not a multi-parameter approach), the change in resonance might instead be taken as a change to the condition of the fault!

Overlapping frequency content

Two or more signals may have a portion of their respective spectral patterns in common (i.e., they overlap). An STA measurement cannot separate these overlapping signals.

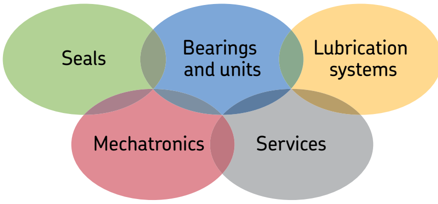
Problems with triggers (felt) and costs

All STA measurements require a trigger source, meaning any asset requiring STA monitoring needs to be equipped with an appropriate trigger device. These devices may be costly or difficult to maintain and keep operating properly. For example, a laser trigger for felt monitoring in a paper machine costs several thousands of US dollars and often gets clogged with pulp, thereby inhibiting its operation.

Synchronous Time Averaging applications

A major application of synchronous time averaging is to isolate the vibration measurements of one machine from a nearby machine running at approximately the same speed. Since the nearby machine's running speed is non-synchronous to the machine under test, its vibration signals will tend to be incoherent with the time averaging function, and will approach an averaged minimum while all signals coherent with the machine reference trigger are enhanced.

STA is most commonly used for balancing as it is the best known technique to deliver steady synchronous amplitudes.



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